

AERONAUTICAL ENGINEERING SERIES

GROUND ENGINEERS

INSTRUMENTS

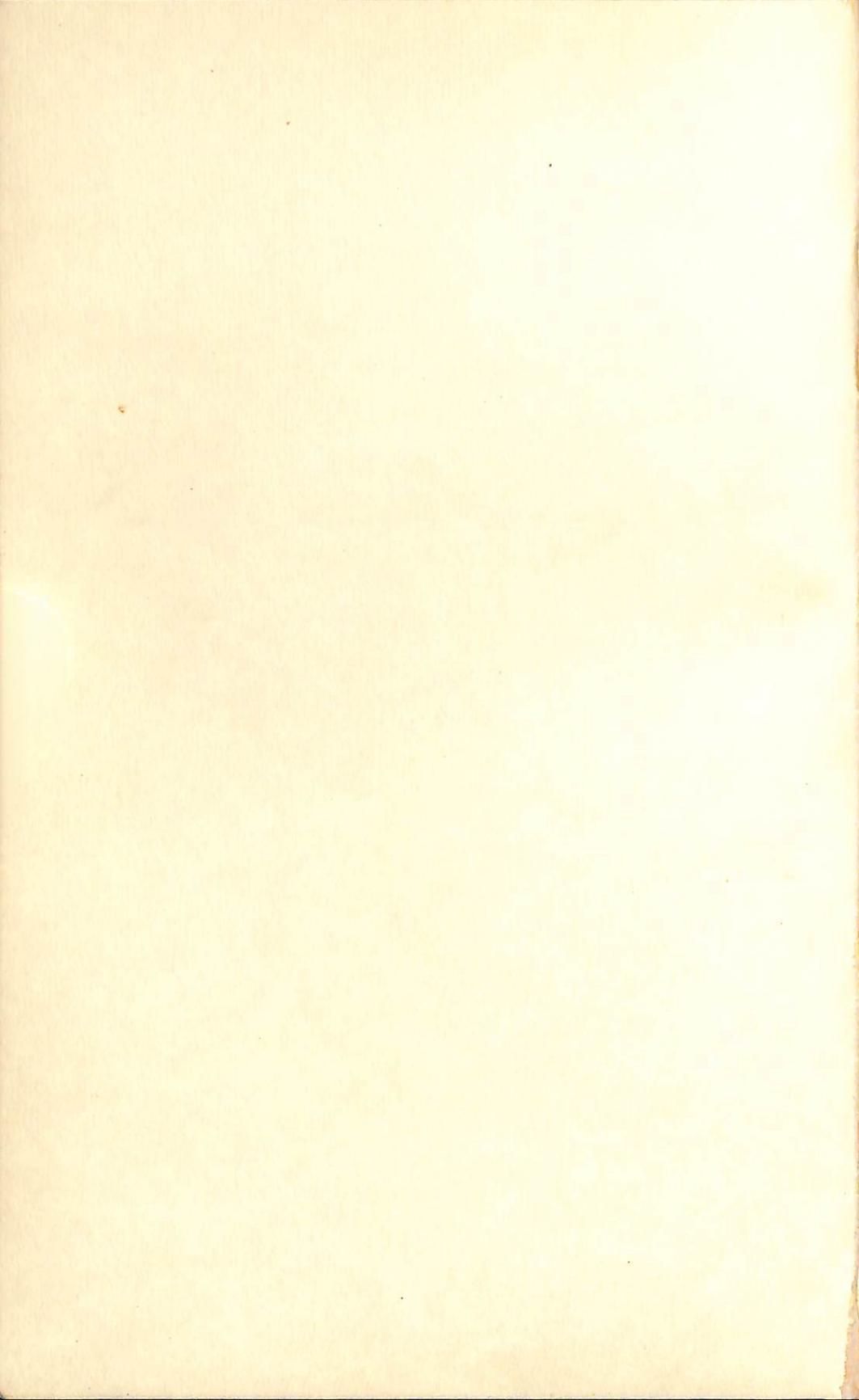
R.W.SLOLEY

G5 260

5/- NET

PITMAN

G5 260



AERONAUTICAL ENGINEERING SERIES

GROUND ENGINEERS

I N S T R U M E N T S

REPAIR, OVERHAUL, TESTING, AND CALIBRATION
OF AIRCRAFT AND AERO-ENGINE INSTRUMENTS;
ADJUSTMENT, INSTALLATION, AND COMPENSATION
OF COMPASSES IN AIRCRAFT

CATEGORY "X" LICENCE

BY

R. W. SLOLEY

M.A. (CAMB.), B.Sc. (LOND.)

G5 260

THIRD AND REVISED EDITION

(Reprinted)



LONDON

SIR ISAAC PITMAN & SONS, LTD.

1940

First Edition, 1934
Second, Revised and Enlarged, Edition, 1935
Reprinted 1936
Third and Revised Edition, 1937
Reprinted 1938
Reprinted 1940

SIR ISAAC PITMAN & SONS, LTD.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE
ASSOCIATED COMPANIES
PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
205 WEST MONROE STREET, CHICAGO
SIR ISAAC PITMAN & SONS (CANADA), LTD.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381-383 CHURCH STREET, TORONTO

CONTENTS

	PAGE
INTRODUCTION	vii
The Duties of the Ground Engineer	viii
Problems of Design	viii
Classification of Instruments	ix
SECT.	
1. THE ENGINE SPEED INDICATOR	1
2. THE PRESSURE GAUGE: (a) FUEL AND AIR GAUGES; (b) OIL PRESSURE GAUGES; (c) BOOST GAUGES	11
3. THE FUEL TANK CONTENTS GAUGE	21
THE FUEL FLOW INDICATOR.	23
4. THE RADIATOR THERMOMETER	23
THE OIL TEMPERATURE THERMOMETER	27
THE AIR TEMPERATURE THERMOMETER	28
5. AIR SPEED INDICATORS.	30
6. INCLINOMETERS: (a) CROSS LEVELS; (b) FORE-AND-AFT LEVELS	40
7. HEIGHT INDICATORS OR ALTIMETERS	42
8. WATCHES	51
9. TURN INDICATORS AND BANK INDICATORS	54
10. COMPASSES	65
*11. THE STATOSCOPE AND RATE OF CLIMB INDICATOR	81
*12. RECORDING INSTRUMENTS	83

APPENDICES

I. STANDARDS	86
II. ERRORS AND CORRECTIONS	87
III. LUMINOUS COMPOUND AND LUMINOSITY TESTS	88
IV. VIBRATION TESTS	90
V. HIGH AND LOW TEMPERATURE TESTS	93
*VI. THE ISOTHERMAL AND I.C.A.N. CONVENTIONS	96
*VII. THE GYROSCOPE	101
*VIII. THE HASLER TEL INDICATOR	105
IX. THE ASHDOWN ROTOSCOPE	110
X. REPAIRS AND ADJUSTMENTS	112
XI. CIVIL INSTRUMENT SPECIFICATIONS	119
OFFICIAL PUBLICATIONS	133

*The sections marked with an asterisk are not essential for the ground engineer, but have been included to meet demands for information which is not readily accessible elsewhere.

ILLUSTRATIONS

FIG.	PAGE
1. Diagram of Engine Speed Indicator Mechanism	1
2. "North" Engine Speed Indicator	3
3. Method of Soldering Flexible Shaft into Connector	5
4. Check Tests on Engine Speed Indicators	6
5. Stroboscopic Testing Apparatus	6
6. "Hasler" Tel Indicator and Recorder	8
7. "Record" Engine Speed Indicator.	8
8. Diagram of Electrical Connexions	9
9. Diagram of "Record" Instrument Mechanism	9
10A. Pressure Gauge Mechanism	11
10B. Fuel Pressure Gauge (<i>Negretti & Zambra</i>)	13
10C. Mechanism of the above	13
11. Oil Pressure Gauge—Transmitting Type (<i>Negretti & Zambra</i>)	14
12. Diagram of Mechanism of Transmitting Type	15
13. Check Test on Fuel Pressure Gauges	17
14. Check Test on Oil Pressure Gauges	17
15. "Dewrance" Dead-weight Tester	18
16. Boost Gauge (<i>Negretti & Zambra</i>)	19
17. Diagram of Boost Gauge Mechanism	19
18. Diagram showing Liquid Level in Radiator Thermometer Bulbs	24
19. Curve showing Vapour Pressures of Ethyl-ether at Various Temperatures	25
20. Curve showing Relation between Boiling Temperatures and Heights	26
21. Oil Temperature Thermometer (<i>Negretti & Zambra</i>)	27
22. Oil Temperature Thermometer (Interior View)	28
23. Method of Looping Capillary.	29
24. Pressure Head (<i>Smith's Aircraft Instruments</i>)	30
25. Diagrams showing Construction of Pressure Heads	31
26. Air Speed Indicator (<i>Smith's Aircraft Instruments</i>)	32
27. Mechanism of Air Speed Indicator	33
28. Pipe Line Joint	36
29. Check Test on Air Speed Indicator.	37
30. Curve showing Relation between Speed and Head of Water	37
31. Calibration of Air Speed Indicator	39
32. Reference Standard	39
33. Cross Level (<i>Smith's Aircraft Instruments</i>)	40
34. Fore-and-aft Level (<i>Smith's Aircraft Instruments</i>)	41
35A. Altimeter (<i>Smith's Aircraft Instruments</i>)	43
35B. The K.B.B.-Kollsman Sensitive Altimeter	45
36. Diagram of Altimeter Movement. Spring Mountings	46

FIG.		PAGE
37.	Altimeter Tests	49
38.	Sectional Diagram of Watch Balance	53
39.	The Axes of the Aeroplane	54
40.	Diagram of Venturi Tube	55
41.	"Reid-Sigrist" Turn Indicator	59
42.	"Reid-Sigrist" Turn Indicator (Interior View)	59
43.	Indications of "Reid-Sigrist" Turn Indicator	60
44.	Diagrammatic sketch of Mechanism of "Brown" Turn Indicator	61
45.	"S.G. Brown" (Type E) Turn Indicator	62
46.	"Brown" Venturi Model Turn Indicator (New Type)	62
47.	"Hughes" Turn and Bank Indicator (<i>Henry Hughes & Son</i>)	63
48.	Diagram of Sperry Horizon	64
49.	"Sperry" Horizon (<i>Sperry Gyroscope Co.</i>)	65
50.	Indications of "Sperry" Horizon	66
51.	Diagram of Directional Gyro	66
52.	Sperry Directional Gyro (<i>Sperry Gyroscope Co.</i>)	67
53.	Compass, O3 Type (<i>Henry Hughes & Son</i>)	71
54.	Compass, "Hughes" Type (<i>Henry Hughes & Son</i>)	72
55.	Compass, K.B.B.4 (<i>Kelvin, Bottomley & Baird</i>)	73
56.	Bubble Statescope	81
57.	Diagram of "Husun" Rate of Climb Indicator (<i>Smith's Aircraft Instruments</i>)	82
58.	Altitude Recorder (<i>Short and Mason</i>)	83
59.	Recording Pens (<i>Negretti & Zambra</i>)	84
60.	Apparatus for Testing Luminous Dials	88
61.	Vibration Table (<i>Negretti & Zambra</i>)	91
62.	The Gyroscope	101
63.	Hasler Tel Indicator Mechanism	106
64.	Diagram of Tel Indicator	107
65.	Chart Record of Tel Indicator	108
66.	Ashdown Rotoscope	109
67.	Pointer Remover	114

INTRODUCTION

IN recent years aircraft instruments have assumed an importance which was hardly anticipated in the early days of aeronautics. A pilot's attention was then wholly occupied in the control of his machine during flights, which were undertaken only in good weather conditions, and even then were of no great length. Training was rightly directed to teaching a pupil to trust to his sense-impressions alone, and to judge of the attitude and behaviour of his machine by the use of his ears and eyes and by what is called the "feel" of the machine. Instruments were few, crude, and unreliable, and a certain distrust of them existed. The impression that instruments are generally unreliable persists in some circles even to this day.

The progress in aviation, as longer cross-country flights as well as flights over water were undertaken, led to the need not only for a greater range of instruments, but for instruments of a more reliable type. When aviation became possible in all types of weather, fair or adverse, the new conditions demanded improved forms of instruments in order that the pilot might supplement his sense-impressions by the indications of his instruments.

It is owing largely to the enterprise of British instrument firms that British aircraft instruments rank among the best to be obtained anywhere in the world. The present stage of development has been reached only after much costly research work. The standard of workmanship and accuracy is now such that it is possible for a pilot to rely on the indications of his instruments when flying at night or in foggy weather. During training a special period is usually allotted to "blind flying," as it is termed, that is, flying by instruments alone, under a hood which prevents the pupil from seeing the horizon and external objects.

Considering the standard of accuracy which has been reached, aircraft instruments are remarkably robust, but it is only gradually being realized that they require and deserve careful handling, and that attention given to installation and maintenance will result in more satisfactory service and longer life. Owing to the relatively severe conditions under which they are used their life is shorter than that of instruments used under ordinary land conditions. It is highly desirable, therefore, that all instruments should be checked periodically for accuracy of calibration, and not allowed to remain in regular use until a defect becomes obvious.

This book has been written with a view to providing the ground engineer with such information as will enable him to carry out his duties so far as they concern instruments, and to get the best possible service from those instruments.

The book is not a treatise on aircraft instruments in general, and the instruments described have been restricted mainly to those which have already been approved by the Air Ministry for use on civil aircraft. Some are obsolescent, but these as well as other types have been included because they illustrate the general principles involved, and the ground engineer is likely to meet with them in the course of his duties.

The writer desires to acknowledge his indebtedness to various aircraft instrument manufacturers who have kindly provided information concerning their instruments and photographs for reproduction, and to his

colleague, Mr. C. E. Dodge, for assistance with Section 8, Appendix X, and in the preparation of the diagrams.

THE DUTIES OF THE GROUND ENGINEER

The ground engineer is required to see that the instruments fitted are of the approved types or comply with the approved specifications, and that they have been duly inspected and approved for calibration, and are in serviceable condition. He must verify that they are correctly fitted in accordance with the installation diagrams and directions. At any time he may be called upon to decide whether an instrument is or is not in a fit condition to be used in the aircraft.

The aim of this book is to assist the reader to prepare himself for this work, which requires knowledge of the methods of inspecting and testing the installation of instruments to ensure correct functioning, and experience in the repair, overhaul, testing, and calibration of the various types of instrument. It is assumed that the reader has a fair knowledge of mechanics and physics, especially of the physics of the atmosphere, and the elementary phenomena of magnetism, which is requisite for the study of compasses. To obtain a certificate in category "X," training in an instrument workshop and experience in a recognized test laboratory are essential. A useful knowledge cannot be gained merely by reading descriptions of the mechanism or studying diagrams in books.

PROBLEMS OF DESIGN

It should be realized that aircraft instruments present a number of special problems to the designer, and some of these will be mentioned in order that the reader may appreciate their importance and bear them in mind while studying particular types. The following conditions must be satisfied in order to ensure correct functioning. They may be regarded as essential features of design—

1. Instruments must be robust in order that they may withstand the vibrations experienced in flight and the shocks of taxi-ing over the ground and of landing.

2. They must not be unduly heavy. Every extra ounce of weight carried is said to add approximately 6s. to the cost of an aircraft. They must be compact in order to occupy the minimum amount of space.

3. The moving parts must be balanced and as light as possible, in order to reduce errors due to tilting, as well as to avoid inertia effects when the aircraft is increasing or decreasing speed.

4. The friction at the bearings must be reduced to a minimum. A slight amount of friction, however, will be overcome by the normal vibration of the instrument panel, and therefore it is permissible to tap slightly instruments under test before taking a reading.

5. Suitable damping of the moving mechanism must be provided, in order that the pointer may take up its position quickly and give a steady reading.

6. The natural vibration period of the moving parts must not bear a simple relation to the natural frequency of vibration of the engine, otherwise its pointer may oscillate violently, making it impossible to obtain a steady reading.

7. The case of the instrument must effectively exclude dust and moisture.

8. The dial must be clearly marked to permit of easy reading by day or, when illuminated, by night. Attention must be given to the dimensions and spacing of the marks to avoid any uncertainty as to the actual reading.

9. The indications of the instrument must be reasonably correct, whatever position is assumed by the aircraft.

10. The readings must not be affected unduly by such changes of temperature as are normally experienced. Some form of automatic compensating mechanism is usually incorporated in the design.

11. The materials must be chosen so as to provide the maximum resistance to corrosion.

12. Instruments must be easy to install and to remove for adjustment or replacement.

CLASSIFICATION OF INSTRUMENTS

The principal instruments used in aircraft may be conveniently classified as follows—

A. ENGINE PERFORMANCE INSTRUMENTS.

1. The Engine Speed Indicator.
2. The Fuel Pressure Gauge.
3. The Oil Pressure Gauge.
4. The Boost Gauge.
5. The Oil Temperature Thermometer.
6. The Radiator Thermometer.

B. AIRCRAFT PERFORMANCE INSTRUMENTS.

7. The Air Speed Indicator.
8. Inclinometers. The Cross Level. The Fore-and-aft Level.
9. The Altimeter or Height Indicator.

C. NAVIGATIONAL INSTRUMENTS.

10. The Turn Indicator.
11. The Compass.
12. The Watch.

Other instruments may be used for special purposes, e.g. the Fuel Flow Indicator, the Fuel Tank Contents Gauge, the Statoscope, and the Rate of Climb Indicator.

Four of the above types of instruments are obligatory for all civil aircraft working under ordinary conditions—

1. The Engine Speed Indicator.
2. The Air Speed Indicator.
3. The Altimeter.
4. Pressure Gauges as necessary.

A compass and a watch are essential for aircraft carrying passengers or goods for hire or reward for flights extending beyond a radius of twenty miles from the point of departure. A turn indicator is necessary when there are more than five seats in the aircraft.

The Air Navigation Directions, 1936 (A.N.D. 13), give particulars of the conditions under which instruments must be carried by aircraft. The approval of the Air Ministry is necessary for the method of installation adopted for an instrument which is a fixture in the aircraft.

Since the first edition of this book was published, Civil Specifications for certain instruments (see p. xii) have been issued. Instruments must comply with these specifications before approval for their use can be given.

In the case of these instruments, approved types are no longer specified by name.

1. Altimeters.
2. Air Speed Indicators.
3. Pressure Head for use with Air Speed Indicators.
- 4A. Engine Speed Indicators.
5. Pressure Gauges for Oil and Fuel Systems.
6. Oil Temperature Thermometers.
7. Radiator Temperature Thermometers.
8. Turn Indicator.
9. Pilot's Magnetic Compass.

These specifications are given in Appendix XI.

Before any new instrument of these types can be installed in an aircraft, a certificate from an approved testing authority must be produced. This must certify that the instrument complies with the appropriate specification. Certain firms are authorized to issue certificates in respect of their own products. Otherwise, a certificate issued by an approved test house is necessary.

In the case of instruments for which a specification has not been issued, or is not applicable, approval of the Air Ministry must be obtained before use.

Types of instruments already approved by the Air Ministry before the issue of the specifications mentioned above may continue to be used until further notice.

For further information as to the conditions of approval, the reader is referred to the *Airworthiness Handbook of Civil Aircraft*, Vol. 1, Leaflets A8, A9 and E1.

INSTRUMENTS

1. THE ENGINE SPEED INDICATOR

THE Engine Speed Indicator, as its name implies, is used to indicate the rate of revolution of the crankshaft of the engine. It is sometimes called a Revolution Indicator or Tachometer, but it must not be confused

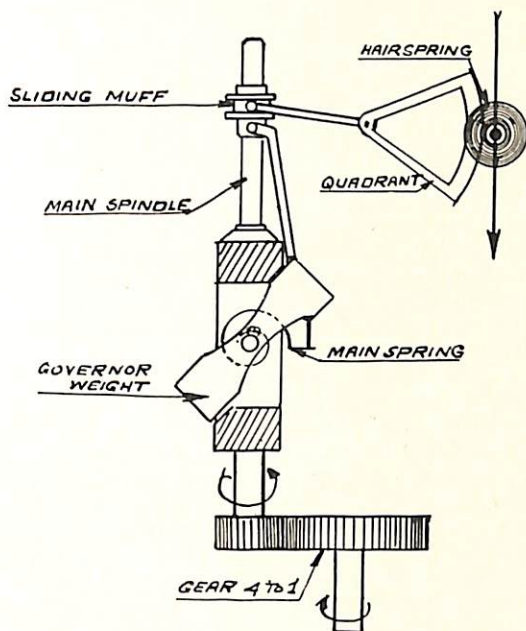


DIAGRAM OF ENGINE SPEED
INDICATOR MECHANISM

FIG. 1

with a Revolution Counter, an instrument which counts the actual number of revolutions.

Knowledge of the number of revolutions per minute of the engine crankshaft is of the utmost importance to the pilot. The power developed by an engine depends on the speed and an engine develops the greatest power at a definite number of r.p.m. This is the best working speed and the engine speed indicator gives a definite and rapid indication of any falling-off in speed and, thus, of the power of the engine. Immediately before a flight, the engine is always "run up" on the ground, and the flight is not commenced until the indicator shows that the necessary adjustments have been made and the engine is working efficiently. The r.p.m. obtained when running up will be less than the correct working speed at full throttle

in the air. In flight, the pilot endeavours to keep the engine running at the correct speed and the indicator enables him to do so and to avoid the danger of overstressing by excess of speed.

The type of instrument in most general use is based on the principle of the "centrifugal governor," invented by James Watt, who first applied it to stationary engines.

The main spindle of the instrument is usually driven at engine speed in order to obtain sufficient control from the governor. The flexible drive operating the instrument is usually run at one-quarter engine speed in order to reduce wear and tear. This arrangement necessitates a gearbox (usually 4 : 1 ratio), which is incorporated in the base of the instrument. A pivoted weight carried by the spindle rotates with the latter, and alters its position as the speed varies. As the speed increases this governor weight (shown in Fig. 1) tends to assume a horizontal position due to centrifugal force, causing the sliding muff to move down the spindle. The tail-piece of the quadrant engages in a groove in the muff and its movements are communicated through a pinion to the pointer which will then move clockwise over a graduated scale. The weight is controlled by a spring, so that it returns towards its initial position as the speed falls to zero. It will be seen that the instrument is designed so that the movement of the pointer is always in the same direction, whether the spindle is rotated clockwise or anti-clockwise. The direction of rotation is determined by looking along the driving shaft *towards* the instrument.

Different makers adopt different methods of arrangement of the governor and actuating mechanism. In the "North" type originally made by North & Sons of Watford, the weight takes the form of a cylinder bored out centrally at right angles to its axis. The cylinder is pivoted to a frame fixed to and rotating with the main spindle, thus acting as a flywheel and damping out movements due to variations in speed caused by whip in the flexible shaft. (Whip is caused by incorrect fitting or insufficient lubrication.) A coil spring is fitted to the transverse spindle which carries the weight in order to restrain the movements of the weight, which are transmitted to the spring by a steel pin nipped between recesses formed in the underside of the weight and the flattened end of the coil spring. The weight is connected to a sliding collar in which the tail arm of the toothed quadrant engages. Thus the quadrant is rotated and turns the pinion on the pointer spindle. A hairspring attached to the pointer spindle reduces the effect of backlash.

In the "Elliott" type of mechanical engine speed indicator, two weights are carried on a rectangular frame, which is pivoted to the main spindle at its centre. The movements of the weights are restrained by an involute coil spring fitted between the side plates of the framework. The lower weight is linked to a collar which slides on the main spindle, and is provided with a groove in which the pin of a crank, carrying at its other end a toothed quadrant, engages. The pinion on the pointer spindle engages the teeth of the quadrant. The action is as follows: As the speed increases, the weight tends to move outwards from the centre spindle, drawing the collar carrying the crankpin up the spindle. The crank is thus rotated, and its movements are magnified by the quadrant and pinion mechanism used to rotate the pointer. A hairspring is attached to take up the backlash in the gearing. Near the top of the main spindle is fitted a light drum, marked on the outer side with a zig-zag line, which can be observed through an aperture in the dial. By this means the observer can ascertain whether or not the engine is running when the speed is so low that no indication is given by the pointer.

The Mark VI instrument is provided with a movable lubber mark, carried on a split ring in the upper portion of the flange which holds the

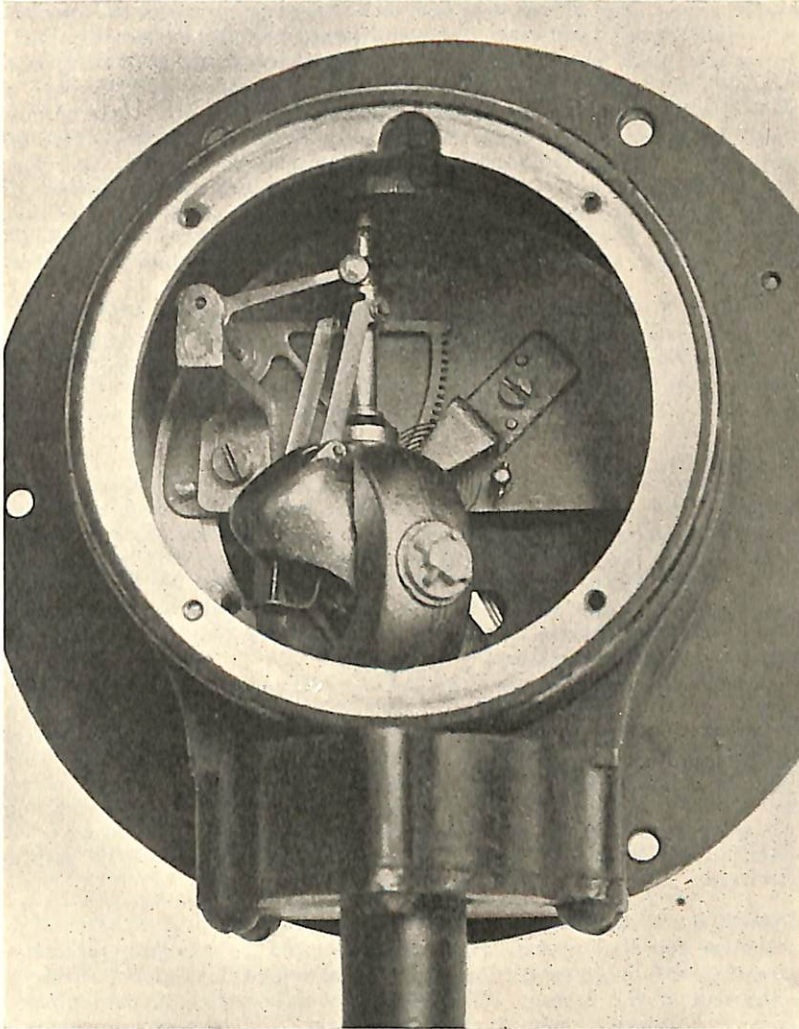


FIG. 2. MECHANISM OF "NORTH" ENGINE SPEED INDICATOR

glass front in position. This split ring can be turned so as to adjust the lubber mark to the normal speed of the engine.

Recent types of engine speed indicators (e.g. Mark IX) are fitted with screwed plugs at the top and bottom of the case, giving access to the grease ducts to the bearings. These are packed with grease during manufacture, and should be refilled occasionally.

The Drive

The indicator is connected to the engine by means of a flexible shaft

(which generally runs at one-quarter engine speed) contained in a flexible casing. The standard drives are Mark IVa (up to 12 ft. in length) and Mark VI (over 12 ft.). Other forms of drive are permitted provided they pass the tests. The cable is stranded, consisting of an inner core surrounded by stranded wire. Four right-hand and four left-hand strands are laid on alternately, until the diameter of the completed shaft is 4 mm. in the Mark IVa or 6 mm. in the Mark VI drive. The ends of the drive are soldered into standard connectors, terminating in short, squared ends, which engage in squared holes in the indicator shaft and the engine connexion respectively. The inner cable runs in a brass flexible outer casing jointed with asbestos to prevent leakage of the lubricating grease. The flexible drive is coupled up to the indicator and gearbox by ordinary coupling nuts. Thirty feet is the greatest length practicable for a flexible drive. If longer, strains are set up resulting in jerky readings as the result of friction.

Flexible drives used with engine speed indicators are provided with vent holes to prevent derangement of the indicator due to the entry of oil and grease forced along the flexible drive by engine pressure. Two vent holes $\frac{1}{8}$ in. in diameter are drilled opposite to one another, in the casing collar at the engine end of the flexible casing $\frac{3}{4}$ in. from the open end.

The Gearbox

When the indicator driving shaft of the engine does not run at one-quarter of the crankshaft speed a gearbox is used to bring the flexible shaft to that speed. Two types of gearbox are employed: (a) the "straight through" type connected by a flexible coupling to the driving shaft, and (b) the "right angle" type, used when the drive must be fitted at right angles to the engine shaft owing to spacing difficulties. The use of a flexible coupling ensures evenness of running and prevents undue wear due to any lack of alignment.

When two indicators are provided for the same engine, a dual drive gearbox is fitted. Two outgoing flexible shafts to the two indicators are driven from one ingoing flexible shaft from the engine. In the gearbox are three parallel spindles each carrying a spur wheel. The central spindle is driven by the engine. Two lugs are provided on the casing for attachment to the aircraft. Mark VI (6 mm.) drives should be used throughout.

Special grease (free from acid or alkali), which does not run at a temperature of $+50^{\circ}\text{C.}$, or become too stiff at -20°C. , should be used for gearboxes.

Installation

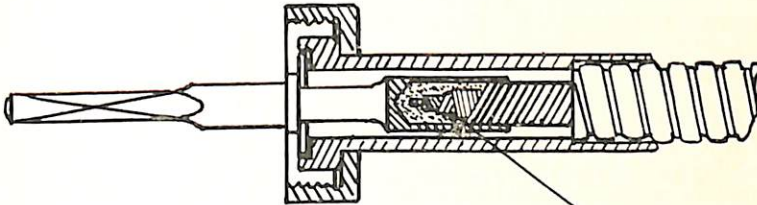
Before installation the flexible drive should be carefully examined. It may be withdrawn from the casing by removing one of the split washers at the end of the casing. When this washer is replaced, care must be taken not to leave it twisted. The shaft must be thoroughly greased with a suitable lubricant. The squared ends should be an easy fit in the corresponding squared holes in the gearbox and the indicator, and should be kept well greased. On no account must the small collar on the squared end bind when the nut is tightened, or jerky readings and possibly breakage of the shaft will result.

It is important that the drive should be installed with as few bends as possible, and in no case should the drive be bent to a radius of less than 9 in., otherwise undue wear will be caused. A test for freedom of the shaft should not be omitted. When one end is coupled up to the indicator it should be possible to turn the shaft from the engine end by

the use of the fingers alone, except perhaps in the case of very long drives. The length of the casing should then be checked and adjusted as necessary to suit the length of the shaft. The adjustment can be made by twisting the casing slightly so that the free end of the shaft does not press too hardly on its washer, nor stand proud more than $\frac{1}{4}$ in. when held close up to the connexion.

Unless absolutely necessary, it is never advisable to attempt to shorten the inner shaft. But if it is essential the following standard method should be employed—

1. Unsolder one steel squared end, heating carefully so as not to impair the shaft by overheating.
2. Cut the shaft to the required length. Before cutting, the shaft



**METHOD OF SOLDERING FLEXIBLE
SHAFT INTO CONNECTOR**

FIG. 3

should be soldered at the point where the cut is to be made, so that the external windings are held. Strip off the layers of wire at the butt in turn by unwinding the outside layer a small amount, and the next layers by decreasing amounts, and fix with solder in each case to prevent unwinding. (Fig. 3.)

3. Clean the bared ends well with emery cloth and petrol, prepare with Fluxite or other non-corrosive flux, and tin thoroughly.

4. Clean out the squared end socket and treat with Fluxite.

5. Heat the socket in the flame of a bunsen burner and fill it with solder.

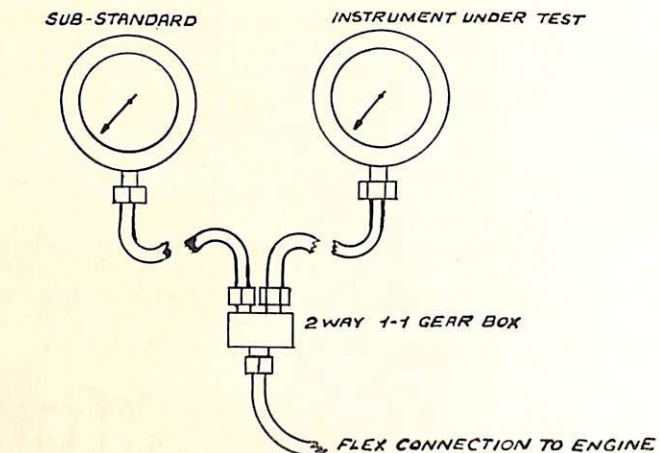
6. When the socket hole and the end of the shaft are well tinned, push the shaft with a twisting motion into the molten solder in the socket.

On no account must the bunsen flame be allowed to play directly on the shaft, as this may reduce its strength to a dangerous degree.

The casing must be securely clipped in position, especially at the bends, so that no unduly long length remains unsupported. If this is not effectively carried out, movement of the part unsupported will almost certainly set up oscillations of the pointer of the indicator.

Unless a special lubricating device is fitted, no lubrication of the indicator should be attempted. The original supply of lubricant to the muff, gears, and main bearings should be sufficient for 300 hours' running. The main spindle should be highly polished and dry. If the accuracy of the readings is suspected, the instrument should be uncoupled and another substituted.

INSTRUMENTS



CHECK TEST ON ENGINE SPEED INDICATORS

FIG. 4

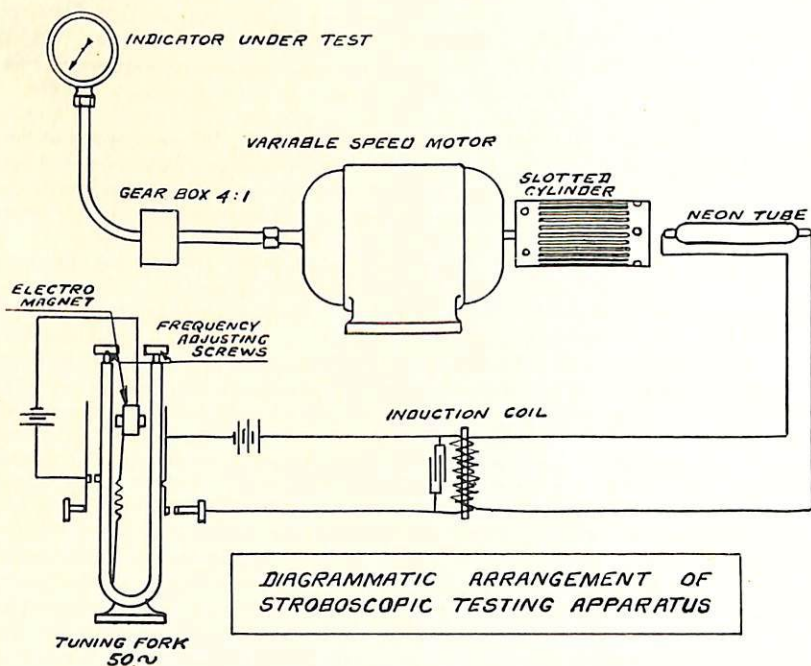


FIG. 5

If these precautions are observed in installation very little trouble should be experienced, and undue wear will be avoided, resulting in longer life.

Check Tests

A simple check apparatus can easily be fitted up if a two-way gearbox, an indicator known to be reliable (or a sub-standard), and a flexible shaft run by a variable-speed motor are available. The two indicators are coupled up to the two-way gearbox, which is run by the flexible shaft driven by the motor. The speed of the motor is varied gradually, and the reading of the instrument under test compared with that of the new indicator. Alternatively the gearbox may be driven direct by the drive from the engine of the aircraft.

Check of Engine Speed

A check on the accuracy of the engine speed indicated may be carried out by a portable rotoscope, such as the "Ashdown" rotoscope (see Appendix IX), when the aircraft is stationary on the ground and the engine running. A clearly visible mark on the propeller boss is observed through the rotoscope, which is adjusted until the mark on the boss appears stationary. The observer then signals an assistant in the cockpit, who notes the reading of the indicator. The error of the indicator is the difference between the observed indicator reading and the actual revolutions per minute as indicated by the rotoscope. By this method an accuracy to 1 per cent should be reached. The necessary correction must, of course, be made in the case of a geared propeller.

Accurate Testing

Accurate checks of engine speed indicators are most conveniently made in a laboratory or test house which is suitably equipped with a stroboscopic apparatus. One form of apparatus may be briefly described.

A variable-speed electric motor running off a constant voltage supply is used to rotate a metal cylinder mounted on its main shaft. Thirty slots, equally spaced, are cut longitudinally in the cylinder, the interior of which is illuminated by a neon tube in the secondary of an induction coil circuit, the primary current of which is interrupted 50 times per second by means of an electrically-driven tuning fork. Thus the neon tube flashes 3,000 times per minute. The duration of the flash is only a few millionths of a second, but owing to persistence of vision the neon tube appears to be continuously illuminated when the motor is not running. Suppose the speed of the motor is gradually raised by means of the coarse and fine resistances provided until it reaches 100 r.p.m. At this speed, light from one flash of the neon tube may pass through one of the slots and enter the eye of the observer. After an interval of $\frac{1}{3000}$ minute the next flash takes place at the moment when the next slot is in line with the observer's eye. Successive flashes take place at instants when successive slots are in the line of sight, and the slots will then appear to be stationary. If the speed of the motor is raised to 200 r.p.m. the same effect is observed, a flash taking place at the instant when every alternate slot is in line with the eye. Thus the stationary effect occurs at every multiple of 100 r.p.m.

If the speed of the slotted cylinder is a little less than an exact multiple of 100 r.p.m., the slots will appear to rotate slowly in the opposite direction to that of the motor. If the speed is slightly higher, the slots will appear to rotate slowly in the same direction as that of the motor. One apparent revolution per minute corresponds to a difference of speed of 1 r.p.m.

The instrument under test is run by the same motor through a gear-box. The speed of the motor can be brought to successive multiples of 100 r.p.m. by observing the stationary positions of the illuminated slots in turn, and the errors of the indicator at each point noted.

Up and down readings are taken, and the direction of the motor can be reversed to allow of such readings being taken for both clockwise and anti-clockwise rotations of the spindle.

The accuracy of the method clearly depends on the accuracy of the tuning fork, which must be checked periodically.

Tel Engine Revolution Indicator and Recorder

The Tel Indicator and Recorder is largely used on British commercial aircraft. It not only records the engine speed and the total revolutions but provides a chart record of the variations of speed during flight along a time scale, governed by an eight-day clock incorporated in the instrument. The instrument is usually fixed in an exposed position, and great care should therefore be taken in installing and clipping the flexible drive to prevent oscillations of the pointer. Recent forms of the instrument



FIG. 6. "HASLER" TEL ENGINE SPEED RECORDER

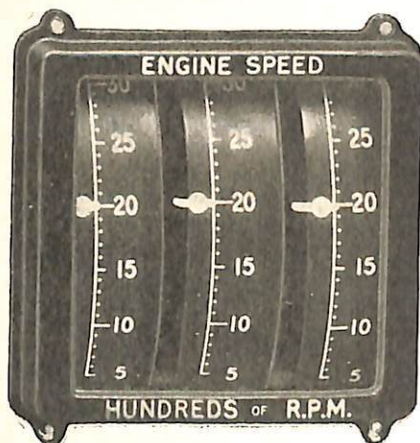


FIG. 7. "RECORD" ELECTRICAL ENGINE SPEED INDICATOR (EDGEWISE TYPE FOR TRIPLE-ENGINE MACHINE)

incorporate agate pointed styles working on semi-transparent varnished paper which avoids paper fluff. No attempt should be made to repair this instrument if the readings appear to be untrustworthy, but the whole instrument should be returned to the makers for overhaul. Further details of the mechanism are given in Appendix VIII.

Electrical Types of Engine Speed Indicators

There are several types of electrical engine speed indicators in use, and they are particularly valuable when it is desired to use an indicator at

a distance from the engine greater than 30 ft., the maximum distance practicable for a flexible shaft. The connexion between the instrument and the generator is made by flexible electric cable, which may be of considerable length.

The principle of construction employed in more than one type is that of an electric generator driven from the engine, either by suitable gearing or a short flexible shaft. The indicator is essentially a voltmeter calibrated to read directly in revolutions per minute and placed in circuit with the generator. As the volts produced by the generator increase with

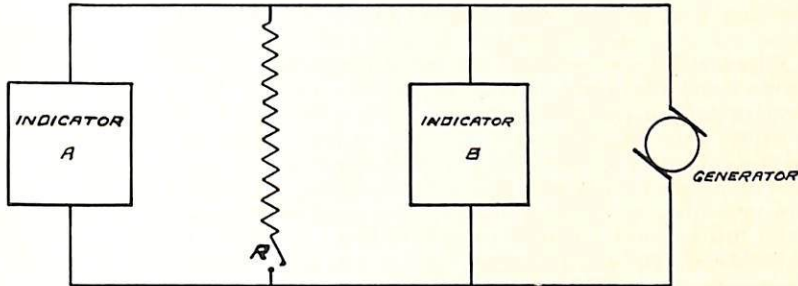


FIG. 8. DIAGRAM OF CONNEXIONS FOR TWO ELECTRIC REVOLUTION INDICATORS WORKING IN CONJUNCTION WITH A SINGLE GENERATOR

If the indicator *B* is not in use, the switch *R* must be closed to include the substititional resistance in the circuit. This resistance is usually incorporated in the generator

the speed, the indications of the pointer on the dial can be made to serve as a measure of the speed.

In the past, electrical indicators have presented special difficulties to the designer owing to temperature errors, and the gradual loss of magnetism

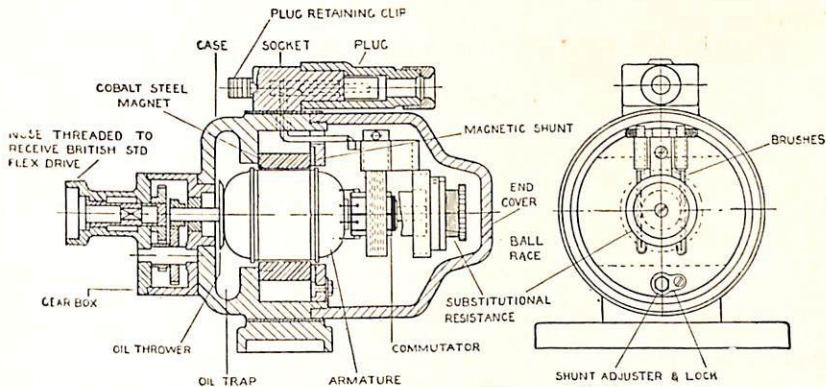


FIG. 9. DIAGRAM OF GENERATOR FOR "RECORD" ENGINE SPEED INDICATOR

in permanent magnets, if these are used in their construction. They are more difficult to construct to the same degree of accuracy or robustness as the mechanical types, and require periodic attention to maintain them in an efficient condition. They should be periodically checked for accuracy of calibration.

The **Record** Electrical Company have developed an electrical indicator used in conjunction with a generator which incorporates a cobalt-steel magnet. In the field of this magnet revolves a multi-pole armature which is standardized to give 30 volts at 3,000 r.p.m. At lower speeds, the voltage output is directly proportional to the speed. Four-to-one gear-wheels are fitted for use with flexible shafts run at one-quarter engine speed. It is advisable, after the generator has been run for about 500 hours, to remove the brushes (conveniently arranged for the purpose) and clean the commutator. Worn brushes should be replaced. No lubrication should be used on the commutator. The bearings and gearbox are packed with special grease to withstand extremes of temperature. The "**Cirscale**" type is the ordinary dial pattern. The "**Edgewise**" type indicator has been designed for compactness, and for easily comparing the speeds of the engines on multi-engine aircraft. It is constructed on the unit principle, each voltmeter being a complete and separate unit with a pointer moving over the edge of the dial which is set edgewise to the observer. Two or more of these indicators are fixed side by side on a base for use with two or more engines. Special plugs and sockets are provided for coupling up to the generators. Any length of flexible cable up to 50 yards may be used without affecting the accuracy of the calibration. The flexible drive used is the same as that for mechanical types, except that the squared ends are $\frac{1}{2}$ in. instead of 1 in. long. Permissible errors are ± 10 r.p.m. on the generator and ± 10 r.p.m. on the indicator.

The "**Weston**" Type 544, E, generator is designed for direct mounting on the engine. It is specially intended for use on engines equipped with standard connexions, and can be screwed and locked in place on the coupling without the need of additional supporting brackets or flexible drive shaft. The indicator is a "**Weston**" voltmeter of the permanent magnet moving coil type with a scale calibrated in revolutions per minute. The makers guarantee an accuracy within 2 per cent for this equipment.

Types

For civil aircraft the following types are permitted—

Mark	Range	Diameter of Dial	Type
	r.p.m.	in.	
Va	600-2,600	4	Mechanical
Vb	600-2,800	4	Mechanical
Vc	800-3,000	4	Mechanical
VI	600-2,600	6	Mechanical
IXa	1,200-3,400	$3\frac{1}{8}$	Mechanical
IXb	600-2,600	$3\frac{1}{8}$	Mechanical
IXd	1,600-4,000	$3\frac{1}{8}$	Mechanical
IXf	2,000-5,000	$3\frac{1}{8}$	Mechanical
Elliott Type XVI	500-4,000	$2\frac{1}{4}$	Mechanical
Pioneer 347	500-2,500	3	Mechanical
Tel.	0-2,500	—	Mechanical
Weston 544	0-3,000	—	Electrical
Record Edgewise*	0-3,200	—	Electrical
Record Cirscale	0-3,000	4	Electrical

* Other types, both twin and triple pointer instruments, of different ranges up to 3,300 r.p.m. are in use.

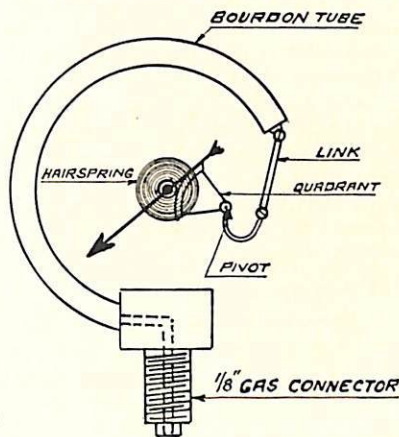
In addition, any instrument may be used which complies with Civil Instrument Specification No. 4A (see page 125), which lays down the minimum requirements for Engine Speed Indicators.

2. PRESSURE GAUGES

The pressure gauges normally used in aircraft are: (a) the Fuel or Air Pressure Gauge—a low range gauge to indicate the pressure of the fuel supply system or of the air pressure system in pressure feed petrol tanks, and (b) the Oil Pressure Gauge, used to indicate the pressure in the engine lubricating system.

The Bourdon Tube

The principle of the Bourdon tube is almost universally used in pressure gauges of the above types. The Bourdon tube takes its name from Bourdon, a Parisian instrument maker, who patented the device in 1850. It consists essentially of a metal tube of oval cross-section, bent or swaged longitudinally into nearly circular form. One end of the tube is closed and free to move, while the other is rigidly fixed and connected to a suitable union for attachment to the fuel or oil pressure pipe lines. Any pressure inside the Bourdon tube, above that of the atmosphere, tends to make the oval section circular and therefore straightens the tube. The free closed end consequently moves through a small distance proportional to the pressure applied. This movement is transmitted by a link and toothed quadrant engaging with a pinion on the spindle of the pointer. The dimensions of the link, the diameter and number of the teeth of the pinion are chosen to give a suitable magnification. A hair-spring is fitted to the pointer spindle to take up backlash, and a stop limits the movement of the Bourdon tube in case of excessive pressure. Another stop is also fitted to prevent the quadrant from accidentally coming out of engagement with the pinion.



PRESSURE GAUGE MECHANISM

FIG. 10A

Fuel or Air Pressure Gauges

The following are types of fuel gauges approved for civil aircraft—

	Range lb./sq. in.	Permissible Error	Maximum Load	Diameter in.
Mark VI	0-5	0.3	15	2
Mark VIa	0-10	0.3	30	2
Pioneer	0-10	—	—	2

Marks VI and VIa gauges are fitted with a lubber mark carried on a

split ring, so as to grip the inside of the instrument case sufficiently tightly to prevent accidental displacement or movement through vibration. This lubber mark should be set to indicate maximum permissible pressure. In general the pressures for fuel purposes range from about 18 in. of petrol, or $\frac{1}{2}$ lb. per sq. in., to 14 ft. of petrol, or approximately $4\frac{1}{2}$ lb. per sq. in., but gauges should be constructed to withstand an overload pressure of at least double the scale range.

Fuel Pressure Gauge (Negretti & Zambra)

A neat type of Fuel Pressure Gauge (of the "Edgewise" type) made by Messrs. Negretti & Zambra is shown in Fig. 10B. The pointer moves over a vertical scale and the space occupied on the instrument panel is only $1\frac{1}{4}$ in. $\times$ $2\frac{1}{2}$ in. The instrument is a transmitting type obviating direct connexion with the fuel supply with the possible danger due to breakage of the connecting pipe or failure of the gauge mechanism. The movement consists of a small corrugated capsule of special design which operates the pointer through a series of spring-pivoted levers. The capsule is connected by tubing (of small bore and small external diameter) to a second "weak" capsule housed in a casing so that the pressure in the fuel system is exerted on it. The indicator—capillary—capsule system is gas-filled and hermetically sealed. The pressure sustained by the "case-capsule" is transmitted to the "indicator-capsule" by the contained gas. The design is such that the variations of external pressure due to altitude do not cause appreciable errors. The capillary is protected by a waterproofed braided cotton covering.

Oil Pressure Gauges

Approved types of oil pressure gauges are—

	Range lb./sq. in.	Permissible Error lb./sq. in.	Maximum Load lb./sq. in.	Diameter in.
Mark Va . . .	0-25	0.8	100	2
Mark Vc . . .	0-100	3.3	200	2
Mark VII . . .	0-25	1.0	100	4
Mark VIIa . . .	0-150	5.0	300	4
Mark VIIa . . .	0-25	2.0	50	2
Mark VIIc . . .	0-100	3.0	200	2
Pioneer 505 . . .	0-120	—	—	$2\frac{1}{4}$
¹ Negretti & Zambra IXc . . .	0-100	2.0	200	$2\frac{1}{2}$
¹ Negretti & Zambra IXd . . .	0-200	2.0	—	—

In addition, any instrument may be used which complies with Civil Instrument Specification No. 5 (see page 126), which lays down the minimum requirements for Pressure Gauges for Oil and Fuel systems.

In the case of all oil pressure gauges, provision is made for overload pressures up to 100 per cent of the scale range. This is necessary owing to the possibility of such pressures being experienced when starting an engine from cold. If the gauge fails, lubrication may be curtailed, with a consequent risk of seizure of the engine. This risk is obviated by the use of the transmitting type of gauge.

¹ Transmitting types.

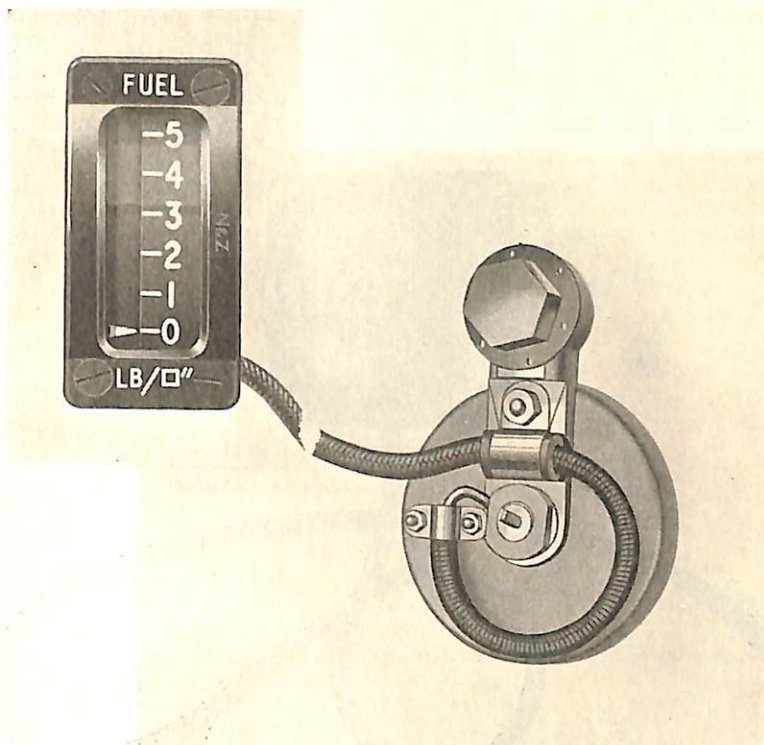


FIG. 10B. FUEL PRESSURE GAUGE
(Negretti and Zambra)

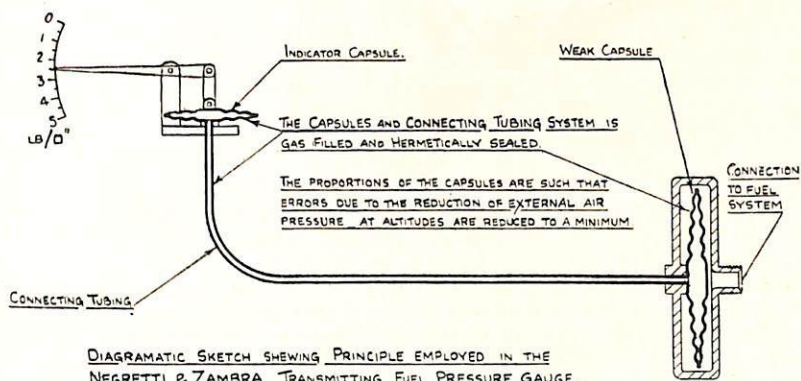


FIG. 10C; MECHANISM OF FUEL PRESSURE GAUGE

Transmitting Pressure Gauge

The Transmitting Pressure Gauge consists of a flexible diaphragm which is connected by means of a fine bore capillary tube to the Bourdon tube of the gauge. The whole system is filled with a suitable non-freezing liquid, such as paraffin or ethyl-alcohol, which acts as a transmitting

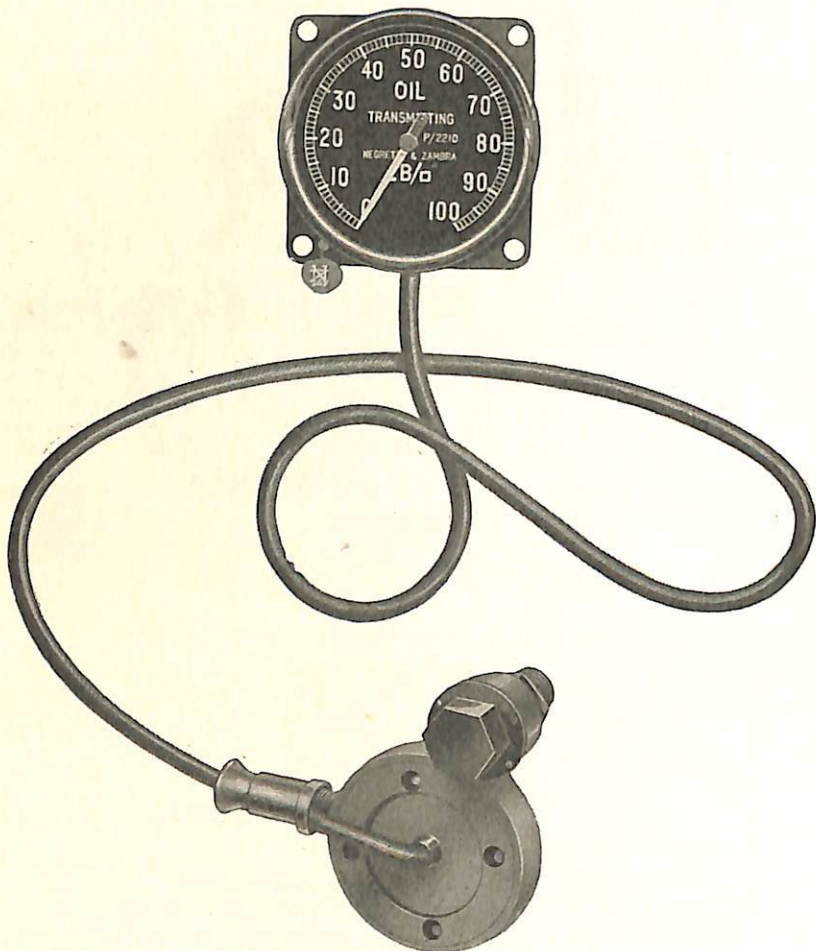


FIG. 11. OIL PRESSURE GAUGE (TRANSMITTING TYPE)
(Negretti and Zambra)

medium to transmit the pressures applied at the diaphragm to the Bourdon tube. The diaphragm is mounted in a suitable case which itself is connected to the oil pump body or other part of the oil supply system remote from the dashboard, and the oil itself is, therefore, entirely isolated from the distant indicator. (See Fig. 12. The oil pressure is applied at *A*.)

The capillary tubing is constructed of well annealed material, such as a copper-nickel alloy (80 per cent Cu.) of external diameter approximately

0.075 in. and bore 0.02 in. It is protected by servings of cotton in two layers wound in alternate directions treated with an approved black wax compound and by a braided outer covering with a further final treatment with the compound. The tubing has to pass the specified bend and fatigue tests.

This type of gauge is chiefly used when comparatively long oil pipe-lines would be necessary, as in the case of multi-engine aircraft where the engines are some distance from the instrument panel. Direct communication between the gauge and the lubricating system is not always advantageous owing to (a) the cooling effect of the long pipe-line in which the

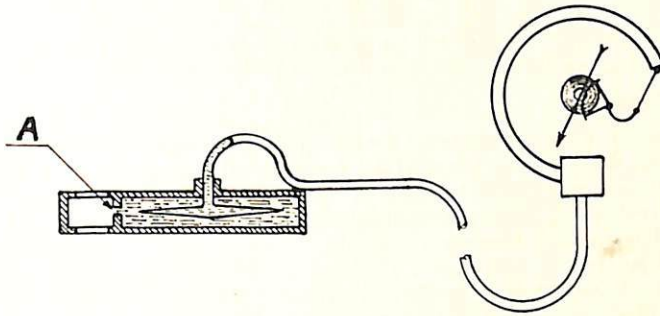


FIG. 12. DIAGRAM OF OIL PRESSURE GAUGE (TRANSMITTING TYPE)

oil might tend to congeal, and (b) the risk of fracture in the pipe-line, with consequent serious leakage of oil.

Installation

When connecting the pipe-line to the direct action type of gauge, care must be taken to ensure that a leather washer of the correct thickness is fitted over the spigot on the gauge connexion, and that there is no risk of this blocking the orifice leading to the Bourdon tube. Before coupling up, the pipe-line should be carefully bent to the gauge connexion in order to avoid strain on the soldered joint between the pipe and the nipple. Before connexion is finally made, the pipe-line should be carefully supported by clips at short intervals along its entire length. Sharp bends should be avoided.

A leak in the Bourdon tube is the most common cause of failure of a gauge. This defect, however, is much less common than formerly owing to the better quality of tubes now made. If the Bourdon tube does leak, the defect will be evident, as the instrument case becomes filled with oil.

If the accuracy of calibration is suspected, the pressure should be released and the gauge carefully watched as the pointer returns to zero. Generally there is no stop at the zero, so the pointer should "float" at this point. If there is no error at zero, large errors of calibration are extremely unlikely.

When installing the transmitting type of oil pressure gauge, the indicator is fitted to the instrument panel, and the transmitting diaphragm box to the oil pump body or other convenient part of the oil supply system.

The capillary should not be uncoiled by pulling it straight out. It should be unwound, care being taken to avoid twisting, and on no account should it be bent sharply round corners.

The diaphragm box is connected to the oil pump casing by means of

a special hollow stud, making sure that the two washers are placed correctly, one on each side of the diaphragm box. The nut should be secured by threading a length of copper wire through the holes in its flange. Copper piping should not be interposed between the diaphragm box and the main oil supply. When the gauge or diaphragm box is subject to engine vibration the capillary should be looped at the point where it leaves the flared end on the gauge or diaphragm box, in such a way that it can be secured by a special clip to the flared end, forming a coil about $1\frac{1}{2}$ in. in diameter. (See Fig. 23.) The capillary should be supported by clips to avoid excessive vibration either from the engine or from the air flow. Special care should be exercised to avoid strain by tension or twisting. It should be clear that the capillary must on no account be broken or disconnected from either the indicator or the diaphragm box or the transmitting liquid will be lost and the instrument rendered useless.

Check Tests

Simple check test apparatus for fuel pressure gauges is shown in Fig. 13. In testing, the level of the water in the U-tube is adjusted to the zero mark on the scale and the tap *A* is then closed. The regulating tap *B* is closed and air is pumped into the air reservoir by means of the pump. By opening the regulating tap *B* cautiously, the pressure can be adjusted so that the pointer of the gauge is brought to any desired mark. The error, if any, is then read off on the U-tube scale, which is calibrated directly in lb. per sq. in. The pressure can be reduced to atmospheric by opening the tap *C*.

Oil pressure gauges may be checked by the simple apparatus shown in Fig. 14. Before the gauge is connected up, the system must be carefully filled with oil by screwing home the plunger of the pump and gradually withdrawing it as oil is introduced into the arms of the tube by means of a special funnel. The gauges under test are then mounted in position and secured by screwing up the nipples. Pressure is applied by means of the screw, bringing the pointer of the standard gauge to different scale marks in turn. The errors of the gauge under test are then read off directly on the dial.

It will be sufficient to take a check at zero, and at one other point of the scale—say about the middle of the scale—in order to dispel any doubt as to the possibility of large errors.

The liquid used in transmitting types of gauge must be such that its vapour pressure at 90°C . is not so high as to cause the instrument to act as a thermometer as well as a pressure gauge. In order to verify this, the indicator may be mounted on a bracket inside an altimeter test chamber so that the dial is visible through a window in front. The capillary passes out through a special split cone gland forming an airtight joint. The capsule is heated in an oil bath to 90°C . and the pressure in the chamber brought to the equivalent of say 40,000 ft. It will be evident immediately if the instrument is acting as a thermometer.

Dead Weight Tests

Full and accurate tests of both ordinary and sub-standard gauges can only be carried out on a dead-weight tester in which the pressures are applied by means of actual weights to the oil in the apparatus, and at the same time the pressures are transmitted to the gauge under test.

The oil can be displaced or forced by means of a screw ram into a cylinder which carries a connection to take the gauge under test in such a position that its dial is vertical. The axis of the cylinder is vertical,

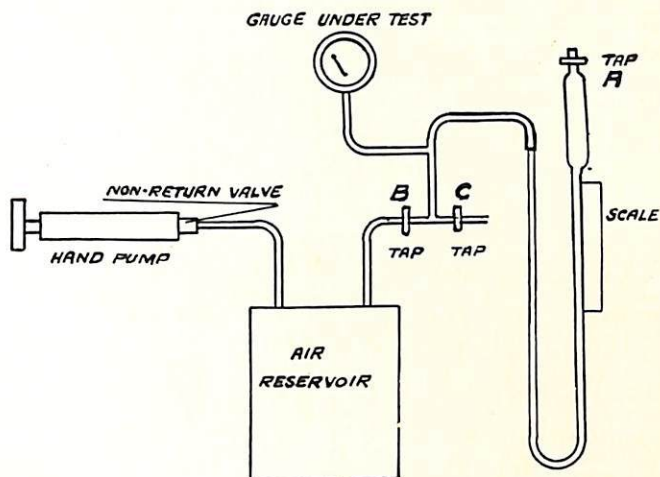
**CHECK TEST ON FUEL PRESSURE GAUGES**

FIG. 13

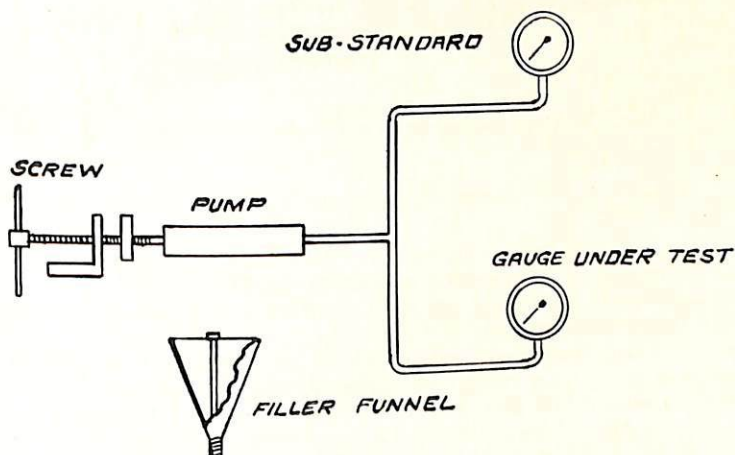
**CHECK TEST ON OIL PRESSURE GAUGE**

FIG. 14

and an accurately machined and fitted piston fits into the bore. The piston carries a support for a disc on which weights can be placed. The area of cross-section of the cylinder bore is usually a definite fraction—say $\frac{1}{8}$ sq. in. The disc is then loaded with weights, each the same fraction of its marked weight. The total weight handled in carrying out a test is thus reduced, since the weight marked 200 lb. is actually only 25 lb., but acting on an area of $\frac{1}{8}$ sq. in. produces a pressure equal to

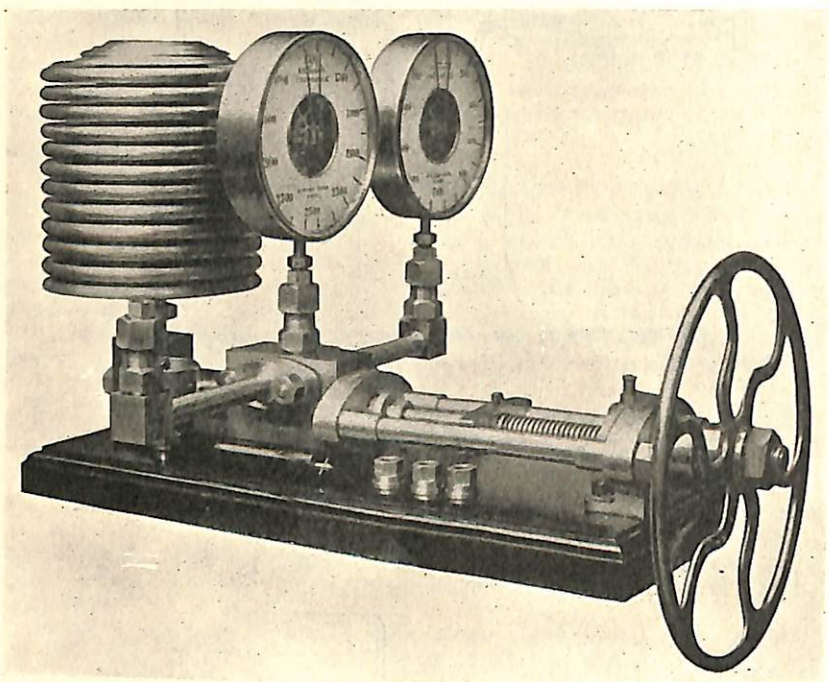


FIG. 15. "DEWRANCE" DEAD-WEIGHT PRESSURE GAUGE TESTER

200 lb. on 1 sq. in. The initial weight of the piston and disc is, of course, taken into consideration when calculating the applied pressure.

The gauge is connected up by a connexion and union nut, a leather washer being used to make a tight joint. The system is then filled with oil as previously described, and the piston placed in position. Weights are added gradually and successive readings taken. An overload test is usually applied to all aircraft gauges, and the maximum load figure given in the table above should be applied. Large alterations in calibration due to the application of the overload pressure must not be permitted, but small differences can be allowed provided the calibration recovers to its normal after twenty-four hours. The total errors must not exceed the figures given in the table above.

In testing a Transmitting Oil Pressure Gauge on a Dead-weight Tester, care must be taken to see that the diaphragm case is at approximately the same level as the top of the oil, or water, column under the dead-weight piston. If there is an appreciably different level, an error will arise, due

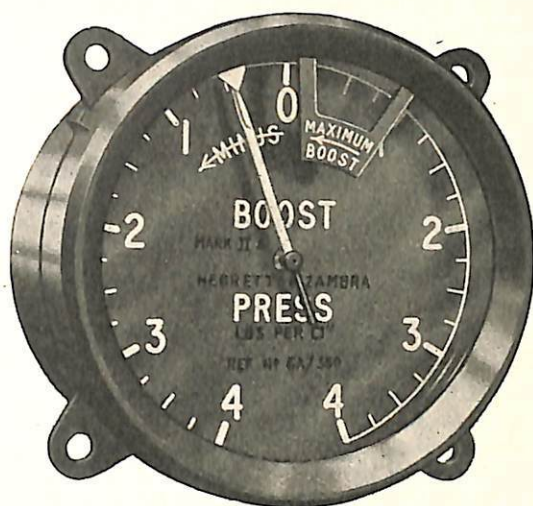


FIG. 16. BOOST GAUGE
(Negretti and Zambra)

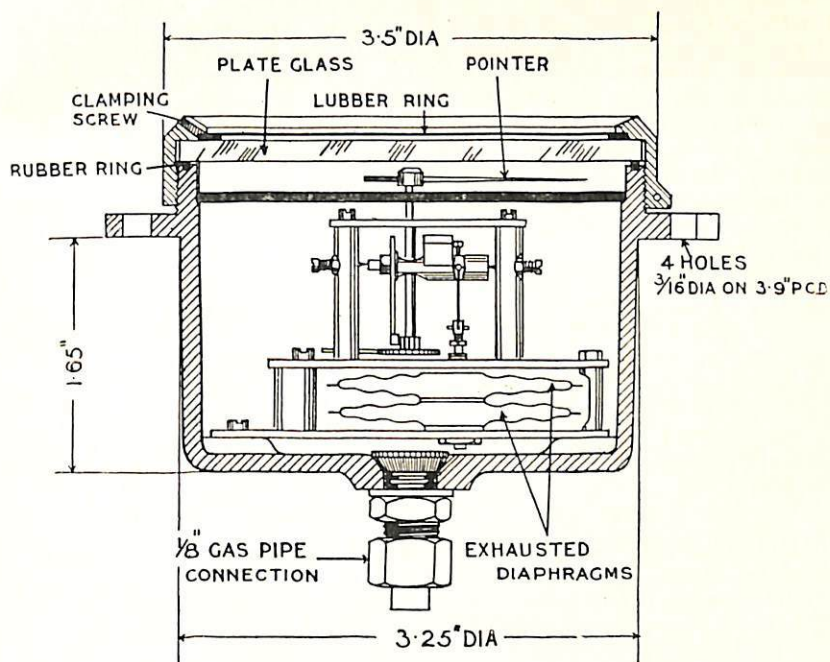


FIG. 17. DIAGRAM OF BOOST GAUGE MECHANISM
(Negretti and Zambra)

to the difference in head of the liquids in the gauge system and in the dead-weight tester.

The Boost Gauge

A boost gauge is used on aircraft primarily to indicate the pressure in the induction pipe of supercharged internal combustion engines relative to the atmospheric pressure at sea-level.

The principle of construction is similar to that of the altimeter (Section 7), except that the case is airtight and provision is made for connecting the interior of the case to the induction pipe of the engine. Special sealing washers, made of petrol-resisting material, are used for the bezel, as rubber deteriorates quickly under the action of petrol vapour. The range of the instrument covers from -6 to $+8$ lb. per sq. in. The pointer should indicate zero at standard atmospheric pressure at sea-level. A small sector over the dial can be fixed from outside, and shows the maximum boost permissible for level flight. This is a safety device to prevent overstressing the engine. It is set for the rated boost of the particular engine for which it is supplied, so that the pilot may regulate the degree of supercharge, within safe limits, when operating the throttle. In one type the setting is carried out by removing the slotted cap-nut in the centre of the glass cover, and turning the slotted spindle thus exposed until the sector is in the correct position. The cap-nut is then replaced. In a later type, illustrated in Fig. 16, the sector can be moved to the correct position by loosening a grub screw at the side of the bezel.

The connexion to the induction system is made by a $\frac{1}{8}$ -in. gas union threaded through the back of the case from the inside. A lock-nut pulls a circular flange hard up against the casing, forming an airtight joint. A gauze filter fits into the union and should be removed periodically for cleansing. Opportunity should be taken to see the pipe-line is free from cracks and the bore is clear. Occasionally a check of the reading should be made by reference to a standard barometer, the reading of which should correspond with that of the gauge when the engine is cold. The following table gives the calculated readings of the gauge at various barometer readings. The error should not exceed $\frac{1}{8}$ lb. per sq. in. between $+2$ and -2 lb. per sq. in., nor $\frac{1}{4}$ lb. per sq. in. over the remainder of the scale.

Barometer Inches of Mercury	Readings of Boost Gauge lb./sq. in.
28	- 0.95
29	- 0.46
30	+ 0.03
31	+ 0.52
32	+ 1.01

The Mark I A Gauge described above is obsolescent. The Mark II Boost Gauge has a "lubber" ring outside the glass and clamped under the bezel. This takes the form of a red shield with white lettering reading "Maximum Boost Level Flight." The central arrow-head is white. The ring is adjusted in position by slackening the locking-screw and moving the shield until the white arrow-head is brought to a position on the scale corresponding with the rated boost figure for the particular engine with which the gauge is to be used. Thus the second indicating line "Maximum

Permissible Boost" on the earlier type of gauge (implying that the normal boost could be exceeded in certain circumstances) is no longer used. In the Mark II Gauge one indication only—that of "Maximum Boost Level Flight"—is given. The range is—4 to + 4 lb. per square inch.

To obviate the possibility of fuel entering the gauge, a fuel trap is sometimes inserted in the pipe system in a position where it is easily accessible. The pipe from the boost gauge is drained into the trap which is provided with a screwed plug for emptying. After draining the plug must be relocked.

Tests on Boost Gauges

Tests on the minus readings are carried out in the same way as those for altimeters; on the plus readings, as those for fuel pressure gauges. A low-reading standard pressure gauge graduated in tenth-lb. per sq. in. may be used in addition to a mercury column. The pointer of the instrument will not always indicate zero at ground-level, owing to variations in atmospheric pressure. During a test, allowance must be made for any difference from the normal by converting the difference into lb. per sq. in. and applying the necessary correction to the readings of the standard gauge.

The special synthetic rubber sealing washers used for the bezel are apt to shrink in service, and if a leak is suspected the sealing wire should be removed and the bezel screwed up carefully hand tight. The setting of the adjustable lubber mark should then be checked, after which the sealing wire should be replaced and secured by soldering.

In some instruments the synthetic rubber washer is replaced by a dished washer inserted between the glass and the bezel. The action of screwing up the bezel tends to equalize the pressure all round the glass and prevent leakage.

A test for leaks may be carried out as follows: The temperature of the instrument is reduced to -20°C . and the external pressure to the equivalent of 35,000 ft. I.C.A.N. (i.e. about 7 in. of mercury). A pressure of 7 lb. per sq. in. is then applied to the boost gauge and shut off. The needle should not fall 1 lb. per sq. in. in less than one minute. As the lubber mark is attached to the glass it is necessary to loosen the bezel and rotate the glass to reset the lubber position. A new method of threading the sealing wire through a small lug on the bezel and giving it an extra turn round the case permits a rotation of rather more than a complete turn without breaking the sealing wire.

3. FUEL TANK CONTENTS GAUGE

The regulations require that—

(a) Provision must be made in all fuel systems to enable the pilot to ascertain when only thirty minutes supply of fuel at full throttle at international r.p.m. remains. The method employed must not be such as to interfere with the functioning of the power plant or plants.

(b) If supplementary tanks are fitted, the pilot must have some indication whether or not the gravity tank is full.

(c) When the fuel supply to the engine is by means of a mechanical pump, a pressure gauge and relief valve must be fitted.

The Fuel Tank Contents Gauge is an instrument of some importance, as it is essential that from time to time a pilot should be able to ascertain the amount of petrol remaining in the tank or tanks. Some difficulty has been experienced by instrument makers in designing a gauge that will

give definite and accurate readings and will not be deranged by vibration, liquid swirl, temperature variations, or unusually violent movements of the aircraft. Owing to varying dimensions of fuel tanks, it is necessary to calibrate the gauges for the particular machine.

Calibration is carried out as follows—

A temporary disc, graduated in degrees is fitted to the dial of the indicator. The aircraft having been set up in normal flying position, the calibration is carried out by first filling and then emptying the tanks in successive stages, the readings being taken in angular degrees. Measurements should be made in stages of 2 gal. in cases when the tank capacity is less than 90 gal. Above this figure, calibrations should be made in stages of the number of gallons equivalent to approximately 5° on the dial of the instrument. A table is then drawn up giving the calibration in gallons and the equivalent readings in degrees on the scale. In order to avoid confusion, the tank drawing number is marked on the dial of the contents gauge.

The Korect Fuel Contents Gauge

The "Korect" type of gauge measures the difference in pressure between the pressure of the liquid at the bottom of the tank and that of the air above the surface of the liquid. By means of a pump, air is displaced from a tube dipping to the bottom of the tank. The lower end of this dip tube is closed by a small float non-return valve, and the pressure required to open the valve against the head of liquid is read on an indicating gauge, connected with the pump, and reading direct in gallons. The gauge is of the "diaphragm" type, similar to an air-speed indicator, and has an adjustment for setting the zero. The dip tube is enclosed in an anti-surge tube communicating with the tank by holes at the bottom and top. Both tubes are telescopic for adjustment and calibration for use with tanks of varying depth. Special precautions are taken in the design to prevent petrol from entering the pipe-line during flight and while a reading is being taken. A pipe connecting the indicator casing to the top of the tank compensates for pressure difference between the indicator and the tank. Recent forms of the instrument embody a small electric motor and air-pump combined, giving the necessary air pressure required so long as the control switch is in the appropriate position. Provision is made for a continuous stream of air along the compensation pipe-line, as well as along the pressure pipe-line between the tank and the gauge. Thus a balance is secured between the static and hydrostatic pressures, and fluctuations of atmospheric pressures are automatically compensated.

The Televel Tank Contents Gauge

The Televel Tank Contents Gauge is of the float type. It is mechanically operated, and the position of the cork float working on the dip tube is indicated on the gauge through a stiff connecting cable, of which the slack can be wound up on a drum by means of an operating handle on the front of the indicator. When not in use, the cable should be fully wound up by rotating the handle slowly and smoothly as far as it will go in the direction of the arrow marked "UP." In use, the handle is turned so as to move the cable down the interior of the dip tube until the plumb-bob at the end reaches the level of the float. The amount of the fuel remaining in the tank is then indicated on the scale, which is exposed through a small window on the dial. The scale is calibrated usually in multiples of 10 gal.

The Bowden cable must be greased periodically and, if the instrument has not been used for some time, the drum must be wound and unwound occasionally to distribute the grease introduced into the Tecalet greasers which are placed at intervals along the cable.

Electrical Fuel Level Indicator

An electrical type of fuel level indicator (developed by *Smith's Aircraft Instruments*) comprises a tank attachment fitted with a float carried on an arm which is connected with a vertical spindle. This spindle is attached to a contact arm travelling over a potentiometer, thus applying varying voltages to a deflecting coil at the back of the indicator on the instrument panel. Readings are obtained when the push button on the front cover is operated.

The Fuel Flow Indicator

The Fuel Flow Indicator is an instrument designed for use in the fuel supply system in order to provide a visible indication of the fuel flowing in the pipe-line in which it is inserted. The Dewrance Prismatic Fuel Flow Indicator consists essentially of a chamber with screwed connexions at each end for coupling up. The chamber is provided with a glass window through which the flow is observed. If the flow of fuel ceases, the liquid in the indicator drains back, and the fact that the indicator is empty is more clearly seen by virtue of the fact that the glass window is prismatic.

4. THE RADIATOR THERMOMETER

The thermometer fitted to all water-cooled engines to indicate the temperature of the cooling water is usually of the transmitting type. It is used to warn the pilot against overheating the engine, and the consequent risk of boiling away the limited amount of cooling water in the radiator system. It also gives a warning indication of the overcooling of the engine, and the risk of freezing the water during a long glide from a high altitude. By adjustment of the opening of the radiator shutters, these effects may be partially or wholly compensated.

The bulb is made of brass or copper and is placed in the uptake pipe of the water jacket or at the top of the radiator, so that the indicated temperature is that of the hottest portion of the cooling water. The bulb is connected to the indicator on the instrument panel by means of a copper capillary tube of approximately 1 mm. bore. The indicator is a pressure gauge of the Bourdon type. The Bourdon tube of the gauge, the capillary tube, and a little more than half the bulb are full of liquid. The rest of the bulb, the upper part, contains only the vapour of the liquid. At the bulb end of the capillary tube, the tube is continued down into the bulb so as to dip below the level of the liquid. (See Fig. 18.)

A liquid which is easily volatile, such as ethyl-ether (boiling point 34.6°C.), is used. Its vapour pressure depends solely on the temperature of the liquid, that is, for every temperature there is one definite pressure which is quite independent of the volume of the bulb. One free surface of the liquid must therefore be in the bulb, and this is achieved by the construction shown in Fig. 18. The bulb is normally the hottest part of the instrument and therefore the capillary and the Bourdon tube fill with liquid, and the vapour above the free surface of the liquid exerts a definite pressure on the liquid surface at every temperature. This pressure is transmitted through the liquid in the capillary to the gauge.

As the temperature rises, the pressure will increase and tend to straighten the Bourdon tube, thus causing a movement of the pointer of the indicator over its dial.

The changes of pressure with temperature are shown in the curve (Fig. 19). Below 40°C . the vapour pressures are small, and for this reason the scale of the instrument usually commences at about 50°C .

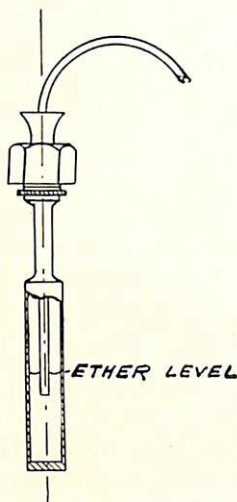


DIAGRAM SHEWING LIQUID LEVEL IN
RADIATOR THERMOMETER BULBS

FIG. 18

The dial of the indicator is marked directly in degrees of temperature corresponding to the pressure reached.

Errors Due to Altitude

Such a thermometer is not accurate under all conditions of service. It is liable to errors due to change of altitude as well as the particular conditions of the installation. The instrument really indicates the difference between the vapour pressure in the bulb and the external atmospheric pressure. The latter diminishes as the height of the aircraft increases. Thus, a thermometer graduated correctly at ground-level will read high when the aircraft rises into the air. An instrument which reads 80°C . at ground-level would indicate roughly 85°C . when the aircraft was at an altitude of 20,000 ft. The error due to this cause is on the side of safety, as the thermometer reads high; but it is usual to allow for this. The boiling-point of water varies with the height. It is the boiling temperature of the water which is the dangerous temperature from the pilot's point of view, as it is his aim to prevent the loss of water by boiling away. It is therefore customary to mark the boiling-points in red, on the dial itself, at the various heights; at the same time allowance is made for the effect of altitude referred to above.

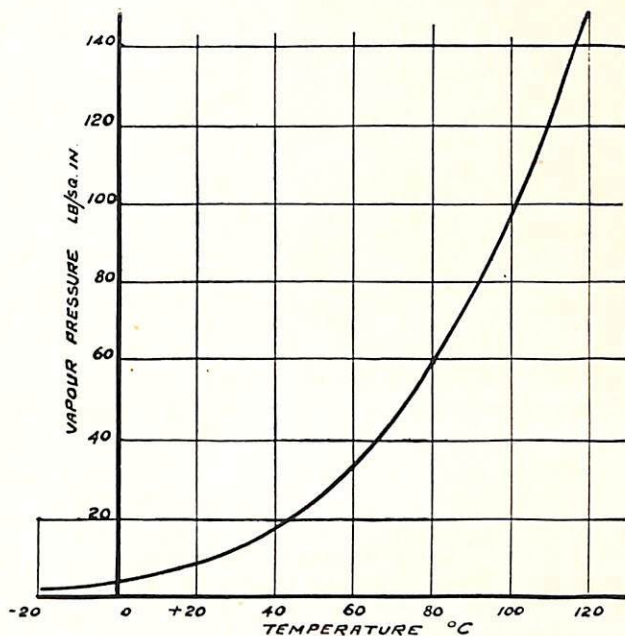
In the diagram (Fig. 20) the apparent boiling temperatures at heights as indicated by the thermometer are given.

Types Approved for Civil Aircraft

The types of radiator thermometer approved for civil aircraft include—

	Range	Dial in.	Permissible Error
Mark Ia . . .	50-100° C.	2	- 0 + 3° C.
Mark VI . . .	50-100° C.	2½	- 0 + 2° C.

Both types incorporate a small tube in the gauge to facilitate refilling. It is closed by flattening and soldering the end. The boiling-point temperatures are marked in red on the dial at multiples of 5,000 ft.



*CURVE SHOWING VAPOUR PRESSURES OF
ETHYL ETHER AT VARIOUS TEMPERATURES*

FIG. 19

In addition, any instrument may be used which complies with Civil Instrument Specification No. 7 (see p. 129) which lays down the minimum requirements for Radiator Temperature Thermometers.

Installation

When installing a radiator thermometer, great care must be taken in handling the capillary. It should be cautiously uncoiled so that no unnecessary strain is placed on the soldered end-joints. It should not be bent more than is absolutely necessary. Careless handling may cause leaks to develop, especially in the neighbourhood of the soldered joints.

A leak is quickly detected by the characteristic smell of ether, and, as ether is highly inflammable, any instrument developing a leak should be immediately removed to a safe distance from the aircraft. On no account must the capillary be disconnected or cut in order to adjust its length. If the tube proves to be too long, the excess may be coiled to a diameter of not less than 6 in. Clips with edges free from burrs should be used to

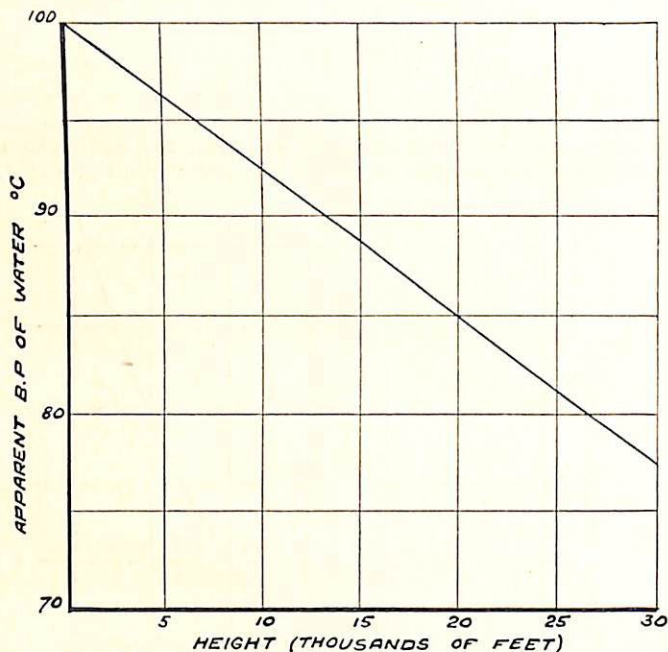


FIG. 20

support the tube at frequent intervals along its length, and every possible precaution taken not to flatten the tube, and to provide against damage due to chafing or vibration. The tube should not be run in the proximity of any part of the engine, where it is liable to get heated, or the accuracy of the readings may be affected.

Check on the Accuracy

If the accuracy of the instrument is suspected, a calibration check should be made in the following way. An ordinary mercury-in-glass thermometer, such as is used in laboratories, is tied to the bulb of the instrument, and the combination used to stir water in a suitable vessel gradually heated by means of a Bunsen burner or other convenient means of heating. The bulb should be immersed to the shoulder and the thermometer to the top of the mercury. Readings should be taken on both scales at intervals as the temperature rises to 98° C. The source of heat is then removed and readings are again taken as the water cools down. The readings are compared and any errors are at once detected. With the indicator and capillary at any temperature between 10° C. and 20° C. and the barometer at 760 mm., the maximum permissible errors are

shown above. The errors due to difference in temperature between indicator and capillary must not exceed 2°C .

THE OIL TEMPERATURE THERMOMETER

The Oil Temperature Thermometer is used to measure the temperature of the lubricating oil in the engine, to avoid overheating, which would impair the lubricating properties of the oil, or overcooling, which would render the oil so viscous that the flow would be impeded. In the case of air-cooled engines the instrument normally provides the only reliable indication of the temperature conditions. For this purpose, the types of thermometer used for indicating temperatures of the cooling water in the radiator are unsuited, as the vapour pressure of ethyl-ether at the lower range of temperature in the neighbourhood of 20°C . is so small that it is difficult to measure with any degree of accuracy. A satisfactory type of instrument, depending on changes in liquid pressure with temperature, has been developed by Messrs. Negretti and Zambra. The bulb, capillary, and Bourdon tube are of steel, and the whole system is completely filled with mercury by exhausting in a high vacuum to remove residual gases, and forcing in mercury at high pressure. The bulb is made of solid drawn steel tube with a flared outlet, into which is welded the steel capillary tube of very fine bore ($.006$ in. diameter) sheathed with a protective copper or braided tubing. Both the bulb and the copper tube are nickel-plated. The fineness of the bore may be judged from the fact that one mile of capillary would contain about $1\frac{1}{4}$ cub. in. of mercury. The Bourdon is made of flat steel tubing of small cross-sectional area, coiled in a double spiral, and itself acts as a spring, thus avoiding backlash. When the bulb temperature is increased a certain volume of mercury is forced into the Bourdon tube owing to the expansion of the liquid in the bulb, and the coiled Bourdon tube tends to uncoil and turn the pointer. The effect of the double coil is to ensure concentric motion about the axis of the pointer and minimize friction. Compensation for changes of temperature is effected by fitting a bi-metallic spiral made of brass and invar strip with the brass outermost. One end of this spiral is attached to the pointer spindle, round which the spiral is wrapped, and the other end is fixed to the free end of the Bourdon. The exposed portion of the capillary as well as the Bourdon tube are at a temperature considerably below that of the bulb. Errors due to this cause are reduced by the use of capillary of very fine bore. When the length of capillary is greater than 20 ft. compensating links may be used. The capillary length is interrupted at intervals by short wider tubes

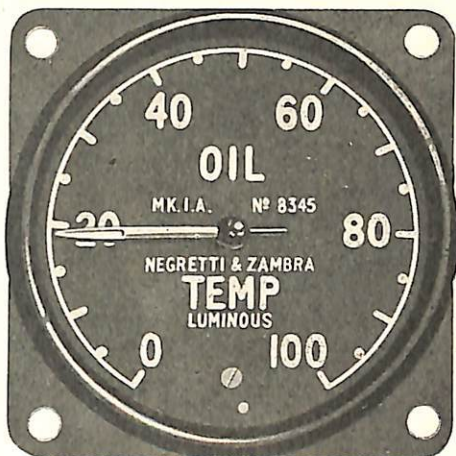


FIG. 21. OIL TEMPERATURE
THERMOMETER
(Negretti and Zambra)

containing invar rods. When the temperature rises, the tube expands, while the invar remains constant in volume. The volume of the space between the invar rod and the tube increases more than the volume of mercury in the "link," and so compensation is effected by suitably choosing the diameter of the bulb and the lengths of the invar rods. Capillary lengths of 100 ft. and above are thus practicable. Owing to the high pressure in the system, the errors introduced in this type of instrument by change of altitude are negligible. The calibration errors should not exceed 1°C. , and errors due to change of temperature between indicator and capillary will not exceed 1.5 per cent for capillaries up to

20 ft., or 2 per cent for those over 20 ft. in length. The lag errors are much less than in the vapour pressure type of thermometer.

The same precautions in installing the instrument are necessary, as have already been described in connexion with the radiator thermometer. The calibration may be checked in the same way. A correction of 0.05°C. should be made for each foot of difference in level between bulb and indicator. This allowance should be reckoned positive when the indicator is below, and negative when above, the level of the bulb. These figures are given as it may be necessary to test the accuracy of the instrument in the cockpit of the machine.

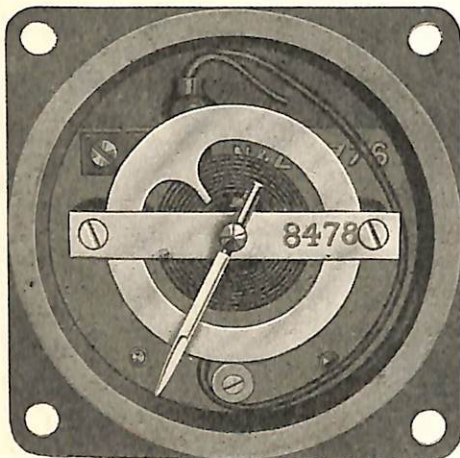


FIG. 22. INTERIOR VIEW OF
OIL TEMPERATURE THERMOMETER
(DIAL REMOVED)

It should be noted that in order to avoid the risk of fracture of the capillary due to too sharp a bend at the bulb end, it is the usual practice for the capillary to be looped and clipped in the neighbourhood of the bulb end, as illustrated in Fig. 23.

The minimum requirements for Oil Temperature Thermometers are laid down in Civil Instrument Specification No. 6 (see page 128).

The "Accoson" types of radiator and oil thermometers—made by A. C. Cossor & Son (Thermometers), Ltd.—are constructed on lines similar to those already described. They work at pressures considerably in excess of normal atmospheric pressure. For example, with a range from 0° to 120°C. the pressure increases from 25 lb. per sq. in. at 0°C. to 640 lb. per sq. in. at 120°C. The effect of change of altitude is therefore negligible. Two liquids are used for filling—one in the bulb, the other in the remainder of the system. They are suitably chosen so that errors due to low temperature are reduced to a minimum.

THE AIR TEMPERATURE THERMOMETER (STRUT TYPE)

As stated on pages 35 and 42, it is necessary to know the temperature of the air, when taking readings of the air speed indicator and altimeter, if

these readings are to be corrected in order to obtain more accurate figures necessary for performance testing, range finding, surveying, or other similar work.

Alcohol-in-glass thermometers are sometimes used for the purpose—the choice of the liquid, alcohol (dyed black or red) depending on its low freezing point ($-130^{\circ}\text{C}.$) and its high coefficient of expansion which facilitates the design of a large thermometer easily readable at some distance from the cockpit. The instrument which is about 2 ft. in length can be fixed by straps to a strut where it is free from the slipstream. The

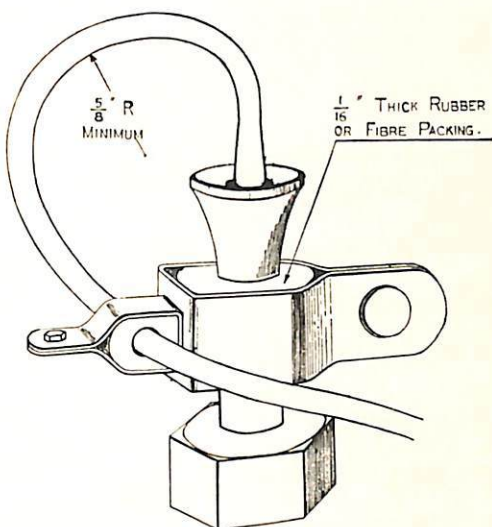


FIG. 23. LOOPING CAPILLARY

bulb is shielded from the direct rays of the sun by a screen, blackened on the interior surface and polished outside. Free circulation of air round the bulb is not interfered with.

THE AIR TEMPERATURE THERMOMETER (TRANSMITTING TYPE)

In the transmitting type air temperature thermometer, a steel bulb (sheathed with copper) is connected by fine capillary tubing to the indicating Bourdon gauge. The whole system is filled with mercury, of which the expansion or contraction during changes of temperature actuates the gauge.

The instrument is provided with a sun shield, and the portion of the capillary in the neighbourhood of the flared outlet at the top of the bulb is looped (as in Fig. 23) to prevent flexing at the joint to the bulb—a point where fracture might otherwise occur, owing to local hardening of the tube during the welding operation. The steel capillary tube is sheathed with braided cotton impregnated with a wax compound. If its length exceeds 20 ft., compensating links are necessary as in the case of the transmitting type of oil temperature thermometers (see page 27).

5. AIR SPEED INDICATORS

A knowledge of the forward speed of the aeroplane is a matter of great importance to the pilot, and the regulations require an air speed indicator to be carried on all aircraft.

An aeroplane is kept in the air by the upward "lift" on the supporting surfaces—the planes. The lift depends on the forward speed of the aeroplane through the air and the angle of attack of the planes to the flow of air past them. If this angle is greater than a certain critical value, lift is lost and at the same time a very high drag or resistance to the forward motion is experienced. The aeroplane then "stalls," and loses height until sufficient forward speed is attained and the attitude of the aeroplane correctly adjusted. The air speed indicator gives a measure of the "lift"

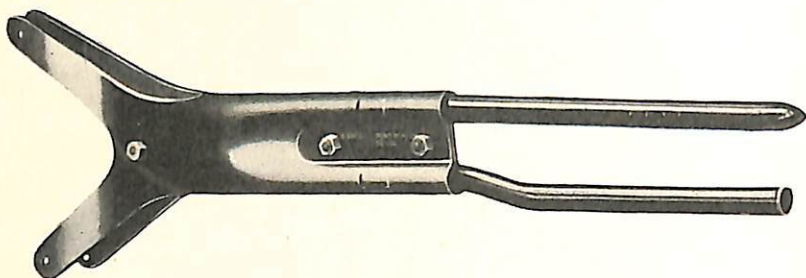


FIG. 24. PRESSURE HEAD (MARK IVa)
(Smith's Aircraft Instruments)

and enables the pilot to anticipate the dangers arising from loss of forward speed. In conjunction with the engine speed indicator, the air speed indicator will give a pilot, who is familiar with his aircraft, guidance as to the fore-and-aft attitude of his machine. Steady readings of both instruments are obtained during level flight in calm air.

The Air Speed Indicator is used to indicate the speed at which the aircraft is moving *relative to the air*. The speed relative to the air must be carefully distinguished from the speed relative to the ground, that is, the speed over the distance travelled as measured on a map. The two quantities are only equal when no wind is blowing. If the reading of the indicator is 80 miles per hour when the aircraft is travelling in the same direction as a wind of, say, 20 miles per hour, the speed relative to the ground will be 100 miles per hour. If the wind is in the opposite direction, the speed relative to the ground (or "ground speed") is only 60 miles per hour.

Civil Instrument Specification No. 2 (see page 122) lays down the minimum requirements for the approval of Air Speed Indicators.

The form of the instrument in most general use is a sensitive differential pressure gauge, mounted on the instrument panel, and connected by lengths of aluminium tubing to a pressure head, attached to a strut on the wing, so as to avoid interference by the slip stream.

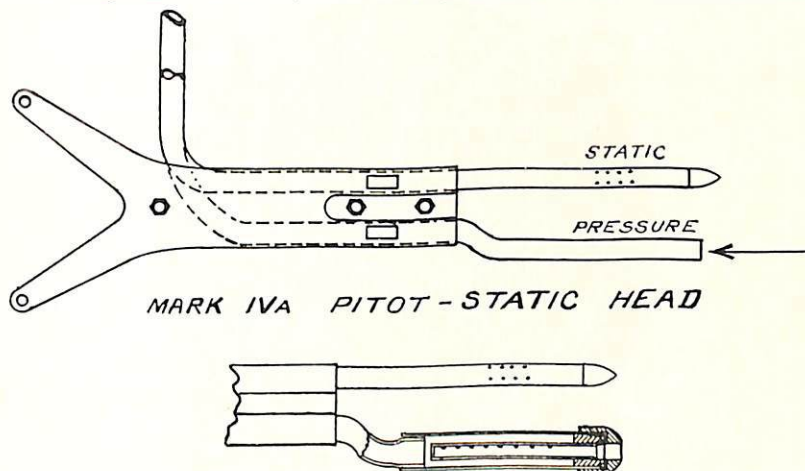
The Pressure Head

The standard pressure head (Mk. IVa) comprises pressure and static tubes mounted parallel and close to one another. The pressure tube is open at the forward end which is exposed directly to the wind pressure, and is connected by a length of aluminium tubing to the nipple of the indicator marked *P*. The upper tube, known as the static tube, is closed and coned at the forward end. It is pierced at a short distance from the

end by a series of small holes, and is connected by another length of aluminium tubing to the nipple of the gauge, marked S. In tropical climates, where the tube is liable to be blocked by sand and insects, a special "trapped" form of pressure head is used (Mark Va). (Fig. 25.) Detailed drawings of an approved form of Pressure Head accompany Civil Instrument Specification No. 3 (see page 124).

The Mark VIIa pressure head has been specially designed to reduce the risk of ice formation, which would interfere seriously with the functioning of the equipment.

The pressure head is based on the same principle as that used by Pitot about 1730 for measuring the speed of rivers. If a tube closed at one end is placed with the open end facing a stream of air, the pressure inside



"TRAPPED" PITOT-STATIC HEAD

FIG. 25

the tube will be greater than the pressure outside. Suppose the difference of pressure is p , then it can be proved from theoretical considerations that $p = k\rho v^2$, where ρ is the density of the air, v the speed of the air flow, and k is a constant. This formula as it stands, does not allow for variations in density, the effect of which is further discussed on page 34. It gives, however, a measure of the "lift" on the aircraft, and is useful in that the stalling speed is indicated by the same position of the pointer, whatever the density of the surrounding air. The indicating gauge, described below, is used to measure the difference between the pressure in the pressure tube (i.e. that of the wind due to movement of the aircraft through the air) and the pressure in the static tube of the surrounding air, if it were still and undisturbed by the motion of the aircraft, as it is, approximately, in the static tube. The static tube moves through the air in the direction of its axis and without greatly disturbing the air owing to the streamline end. Thus the air passes over the holes in the side of the tube at right angles to their direction. It has been proved by experiment that the pressure inside the static tube is very nearly the true pressure outside whatever may be the velocity of the tube.

The Indicating Gauge

The most usual form of gauge consists of an airtight case, connected to the static nipple, marked *S*. An elastic metal box with thin corrugated sides is fitted inside the case, and its interior connects with the pressure nipple (marked *P*) on the outside of the case. This box is usually made of nickel-silver, and is supported in an aluminium frame carrying a transverse shaft with two short balanced arms mounted across it. One of these arms is connected to the side of the box or diaphragm. The other arm actuates a toothed quadrant by means of a crank. A pinion on the pointer spindle meshes with the quadrant, and the usual hairspring is fitted. The pressure of the air in the pressure tube is communicated to the

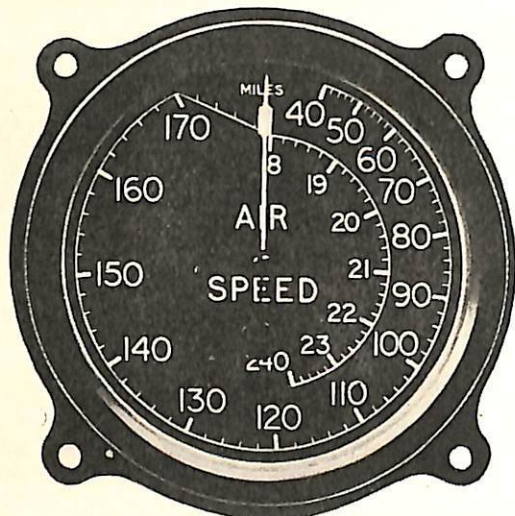


FIG. 26. AIR SPEED INDICATOR
(*Smith's Aircraft Instruments*)

interior of the diaphragm box, and as it varies causes corresponding movements of the pointer, through the mechanism, over the dial. Metal diaphragm instruments such as the type described above give satisfactory performance over a wide range of temperature.

The older type of indicator was fitted with a transverse diaphragm of oiled silk or thin leather, dividing the case of the instrument into two distinct airtight compartments connected respectively with the pressure and static nipples on the exterior. Changes of pressure cause movements of the diaphragm, which are communicated to the pointer by suitable mechanism. A disc, with a central spindle, is fitted to the centre of the diaphragm. The end of the spindle is in contact with a leaf-spring actuating a bell-crank lever, one arm of which projects through a slot in a metal plate pivoted on an axis parallel to the pointer spindle. A quadrant, forming one end of this plate, engages a pinion on the pointer spindle.

An indicator with an oiled silk diaphragm is very sensitive, but its useful life is short, especially if subjected to high temperatures. The material is not suited to tropical conditions. On the other hand, instruments with metal diaphragms are not seriously affected by changes of temperature.

Great improvements have been made in recent years in the construction of metal diaphragms and diaphragm boxes. Nickel-silver (Grade A) is usually employed, and after rolling is pressed into the desired shape, so that the minimum amount of solder is necessary to close the box finally. The solder must be applied only at the extreme edge of the box to avoid interference with its elastic properties. The nickel-silver disc is usually rolled to a thickness about 16 per cent above the final thickness. It is then annealed and rolled and cross-rolled by stages, to eliminate the effect of grain and

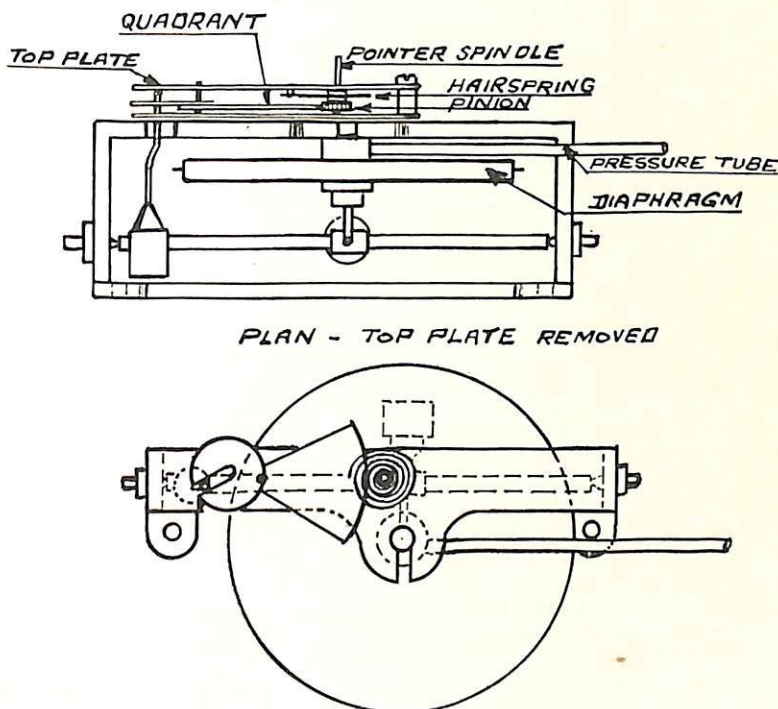


FIG. 27. AIR SPEED INDICATOR MECHANISM

reduce the risks of cracking during the pressing process, until the final thickness is obtained. Corrugated diaphragms are formed in a press with a single die, a rubber sheet being interposed between the disc and the plunger of the press. The diaphragms are aged before use.

Whatever the material of the diaphragm, it is essential that the cases of the indicators be airtight. This is effected by providing a rubber ring which can be compressed by screwing up the bezel ring. Leakage on the pressure side may introduce serious errors in readings. Small leaks on the static side may be permitted. (See, however, page 116.)

It should be noted that the speed indicated is that of the pressure head, and if the head is fixed at some distance laterally from the centre line of the machine, as is usually the case, errors will be introduced during turns, when the wing on the outer edge of the curve moves faster than the inner wing. However, the errors introduced are not serious except on very sharp turns.

Problems of Calibration

The dial of the indicator is calibrated so as to read directly in miles per hour or in knots (1 knot = 1.152 m.p.h.). It has already been stated that, in general terms, the pressure difference operating the mechanism is proportional to the square of the air speed. The pressure difference is usually expressed in millimetres of water—namely the height in millimetres of a column of water which would produce the same pressure.

Now if p = the pressure difference in millimetres of water

ρ = the density of air in grm./c.c.

g = the acceleration due to gravity in cm./sec.²

d = the density of water in grm./c.c.

c = the constant for the pitot-static head

v = the speed of the air in miles per hour

it can be shown that

$$p = \frac{9992 \cdot 24 \cdot \rho \cdot c}{gd} v^2$$

It remains to substitute values of ρ , c , g , and d . Substituting $\rho = .001221$, $c = 1$, $g = 980.62$, and $d = .99912$, we find that $p = .01243v^2$, or if v is measured in knots, $p = .01648v^2$. The value for ρ is an average value obtained by experiment.

Recently, the adoption of the International Standard Atmosphere has resulted in the density of the air being reckoned on a new average basis, and taking the new value .001226 we obtain

$$p = .01250 v^2 \text{ (miles per hour) and } p = .01658 v^2 \text{ (knots).}$$

Most modern air speed indicators are calibrated on this uniform basis. The International Standard Atmosphere is used as a reference atmosphere in aircraft performance tests, and all figures of performances can be reduced to what they would have been had the atmosphere been standard at the time of the tests. The full details of the scheme are given in the Official Bulletin, No. 7 (O.B.7), of the International Commission for Air Navigation.

By substituting values for v in the formulae quoted above, the corresponding pressures in millimetres of water can be obtained. These can be set out in the form of a calibration table.

Corrections

At high speeds (above 200 m.p.h.) it is necessary to correct the figures for compressibility of the air.* The method of calibration already described

* The formulae then used are—

$$p = .01250 \cdot v^2 (1 + 0.43 v^2 \times 10^{-6}) \text{ m.p.h.}$$

$$\text{and } p = .01658 v^2 (1 + 0.57 v^2 \times 10^{-6}) \text{ knots.}$$

For comparison, the corresponding pressure differences at four speeds are set out in the following table—

Air Speed m.p.h.	Pressure difference in mm. of water using Standard head		
	On old density basis	On new density basis	Corrected for Compressibility
80	79.6	80.0	80.2
100	124.3	125.0	125.6
150	279.7	281.3	284.0
200	497.2	500.1	508.7

assumes that the density of the air is uniform and equal to the value given above, either on the old or the new basis. Now the true density of the air depends on both the temperature and the pressure, both of which decrease as the aircraft gains height. The distribution of the temperature and pressure in the atmosphere is a complex problem. From data collected over a long period, it has been found possible to provide formulae from which the values of pressure and temperature can be calculated at any given height. The results are only approximate, as local variations are not taken into account, but they serve for all practical purposes.

The errors to which instruments are normally subject, such as those due to temperature changes, are considerably greater than those due to the use of the approximate formulae. The same formulae are used to reduce experimental measurements to standard atmospheric conditions in order that they may easily be compared with each other.

The earlier "isothermal law" for the distribution of temperature and pressure assumed that the temperature was constant at all altitudes. The I.C.A.N. convention assumes that the temperature falls 1.98°C . for every thousand feet rise up to about 30,000 ft., and thereafter remains at a constant value.

Computers in the form of a circular slide-rule are used for correcting air speed readings when great accuracy is required. (See also p. 100 and Appendix VI.)

Although the present form of air speed indicator has been improved considerably of recent years there is pressing need for an instrument in which automatic compensation is made for changes in altitude and atmospheric pressure.

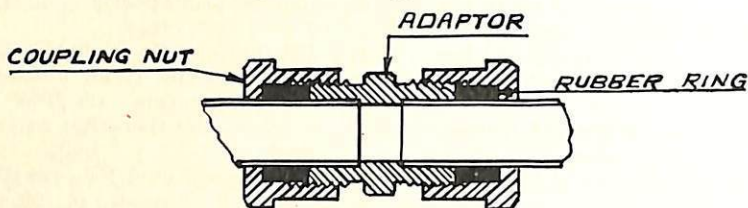
Installation

The installation of an air speed indicator must be carefully carried out. The pressure head (pitot-static head) should be placed in a position as free as possible from air disturbance. At the same time it must be conveniently situated so as not to be liable to accidental damage. The best position has been found to be about two-thirds of the way up the outer front inter-plane strut. It should be adjusted so as to be horizontal when the main plane chord is inclined about 3° to the horizontal. This adjustment minimizes the variations due to change of trim as the speed is varied. The variations are not serious for angles less than 10° . The edge of the pressure tube must be smooth and circular, and the small holes in the sides of the static tube must be free from burrs or dirt, which would prevent the air inside from quickly taking up the average pressure of still air. The head should be placed so that the pressure (bent) tube is below the static tube. The "set" in the pressure tube is introduced so that as much moisture as possible will drain off. The "trapped" pressure head, if used, should be unscrewed and cleaned periodically. Care must be taken to ensure that it is correctly reassembled with the word "top" uppermost. Finger pressure only should be used to tighten the knurled brass cap in order to avoid straining the tube and joints.

The aluminium connecting tubing should be run inside the wing or fuselage as far as it is possible to do so. It is important to avoid all restrictions in the pipe lines, which would produce false readings. If joints are necessary, special attention must be paid to ensure that the joint is airtight. There are several types of joint in use. In one method, the ends of the tube, filed smooth to face at right angles to the axis of the tube, are butted together and sleeved by a short length of tubing of slightly larger diameter which fits closely. The joint is completed by short lengths of

rubber tubing allowing overlaps of at least 1 in. Owing to the rapid deterioration of rubber, especially in tropical climates, such joints need to be remade periodically.

Joints can be made with all metal fittings. The ends of the tubing to be joined are inserted in an "olive"—a short piece of aluminium tube tapered at the ends. This is tightly gripped on to the butted ends of the tubes by coupling nuts which are screwed on to a sleeve. The screw threads are tapered so that a very tight grip is obtained. This joint suffers from the disadvantage that the olive bites into the ends of the soft aluminium tube, which must be cut away if it is necessary to disconnect and remake the joint. An improved form of this joint is in use. A rubber ring and a special coupling nut are slipped over the ends of the tubes to



AIR SPEED INDICATOR PIPE LINE JOINT

FIG. 28

be joined, and an adaptor made of duralumin is fitted over the ends. On screwing up the nuts, the rubber rings are held tightly compressed, and make an airtight joint. (See Fig. 28.)

From time to time the tubing must be disconnected from the instrument and the head, and condensed moisture and dirt blown out by a stream of air from a pump. A test for leaks may be applied to the system as installed. A simple method is to attach a short piece of rubber tubing to the pressure head tube and to blow *gently* down the tube until the indicator gives a reading of, say, 100 m.p.h. The rubber tube is then pinched and the indicator watched to see if the pointer moves back towards the zero. If a leak manifests itself the indicator should be disconnected and tested separately in the same way to determine if there is a leak in the diaphragm. If not, the leak will be located in the pipe-line. The static side can be tested similarly by gently sucking air out and pinching the rubber tube. In each case the tube should not be less than 10 in. in length in order to avoid the deposition of moisture from the breath.

When the indicator has a "floating" zero, the position of the pointer is not determined by any stop in the mechanism. Normally the pointer is approximately vertical (either up or down) when no pressure is applied. Thus, an error in calibration is indicated if it assumes any other position.

Check on Accuracy

A simple U-tube manometer may be used to check the accuracy of the gauge if this is suspected. The apparatus is shown in the sketch (Fig. 29). Pressure from the air reservoir can be applied both to the manometer and the instrument under test by means of the T-joint. The water in the manometer is adjusted to the zero marks and the tap *C* is closed. Air is then pumped into the reservoir by the pump—a rubber bulb fitted with a non-return valve may be used—and the tap *A* closed. The tap

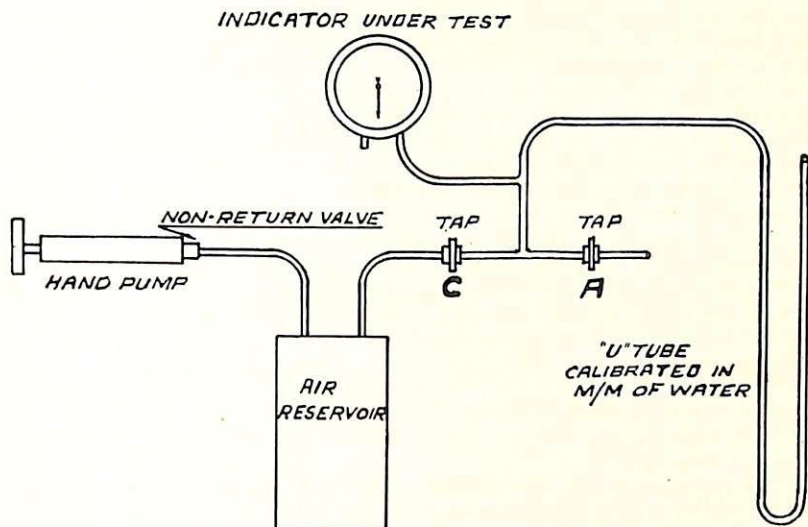
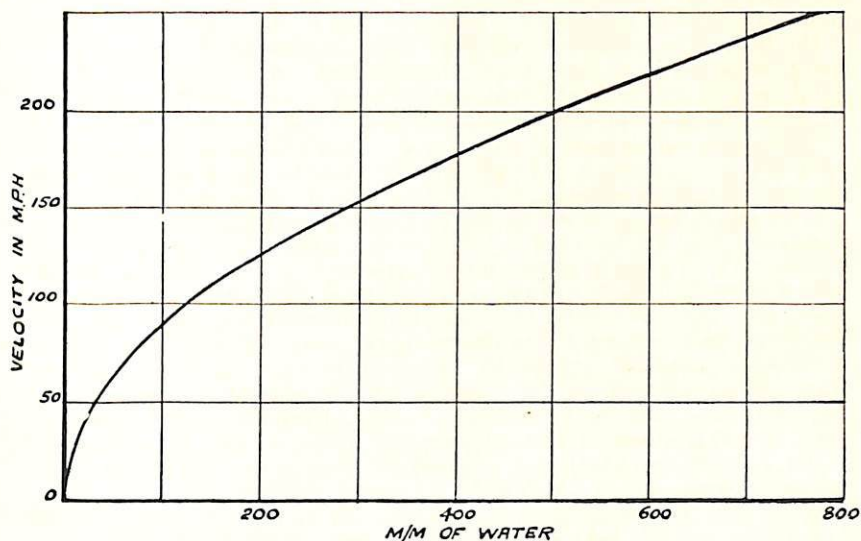


FIG. 29



MARK IVA AIR SPEED INDICATOR - PRESSURE IN M/M OF WATER
EQUIVALENT TO VELOCITY IN M.P.H. - $P = 0.01249 V^2$

FIG. 30

C is then cautiously opened, thus applying pressure to the manometer and the instrument at the same time. The pressure is measured in millimetres of water by the difference in level in the arms of the U-tube. The error, if any, is found by reference to a calibration table. It is convenient to graduate the U-tube directly to read miles per hour. The curve (Fig. 30) will serve to give some idea of the relation between the miles per hour readings and the "head of water" measured in millimetres. The tap *C* is conveniently made as a three-way tap, providing an opening direct to the atmosphere, so that the pressure can be reduced when necessary.

The instrument should be accurate to within plus or minus 2 m.p.h. at ordinary room temperature with the dial vertical. (See p. 123.)

The same pressure head may be used to actuate two or more indicators, in the pilot's cockpit and the passenger cabins, by using T-joints to join up each indicator with the pipe-lines.

Tests

Accurate tests of an air speed indicator can only be carried out on a sensitive manometer, which is itself checked periodically by means of a reference standard.

The manometer consists essentially of two concentric cylinders containing water, which is free to pass from one to the other through openings at the bottom of the inner cylinder. The outer cylinder is closed and provided with a tap so that air under pressure can be introduced, thus lowering the water-level in the outer cylinder and raising the water-level in the taller inner cylinder. Another tap opens to the atmosphere, and is used when it is necessary to release the pressure. A float on the water in the inner cylinder is connected by a chain operating on a spiral arbor fixed to a pointer spindle in such a way that the chain is either wound up on the spiral or unwound from it, according to the direction of motion of the float. The pointer moves over a dial calibrated in millimetres of water, miles per hour, and knots in concentric scales. The form of the spiral arbor is chosen so that the scale is as open as possible at the lower readings, where the movement of the pointer would be otherwise small.

For precise adjustment of the zero, there is provided a screw displacement plunger working in a small cylinder fixed to the side of the outer cylinder, and communicating with it by a tube in which is fitted a tap.

Connexions are provided for the instruments under test, and the pressure is obtained by means of a pump with a capacity reservoir. Control valves are conveniently placed for the operator. In carrying out a test, the valve controlling the pressure is opened so as to allow the pressure to increase until the pointer of the instrument under test has covered the whole range and returns to the datum-mark, if any. The pressure is then decreased by gradually opening the valve which is open to the atmosphere, until the pointer again reaches zero. During the process the behaviour of the pointer is watched. It should move smoothly and freely over the scale without sticking, and should consistently stand at the same distance from the dial throughout the movement. It should not be so far from the dial as to cause serious parallax errors, nor so near to the glass as to risk contact. The zero reading should be checked against the sub-standard manometer and the pressure gradually increased in steps, so that the pointer of the manometer stands successively at convenient scale divisions corresponding to exact multiples of 1 m.p.h. The error of the instrument under test at each point is read off and recorded. After reaching the maximum reading, down readings are taken in the same way, under gradually diminishing pressures.

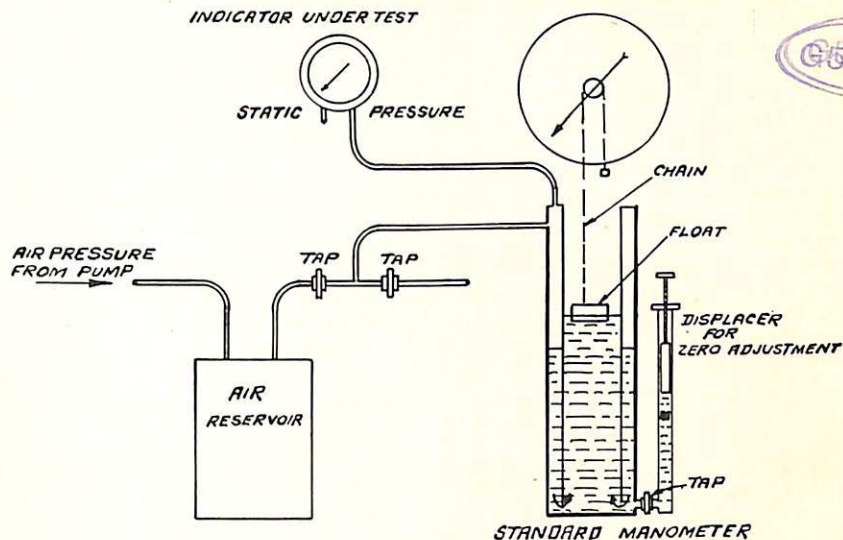


FIG. 31. CALIBRATION OF AIR SPEED INDICATOR

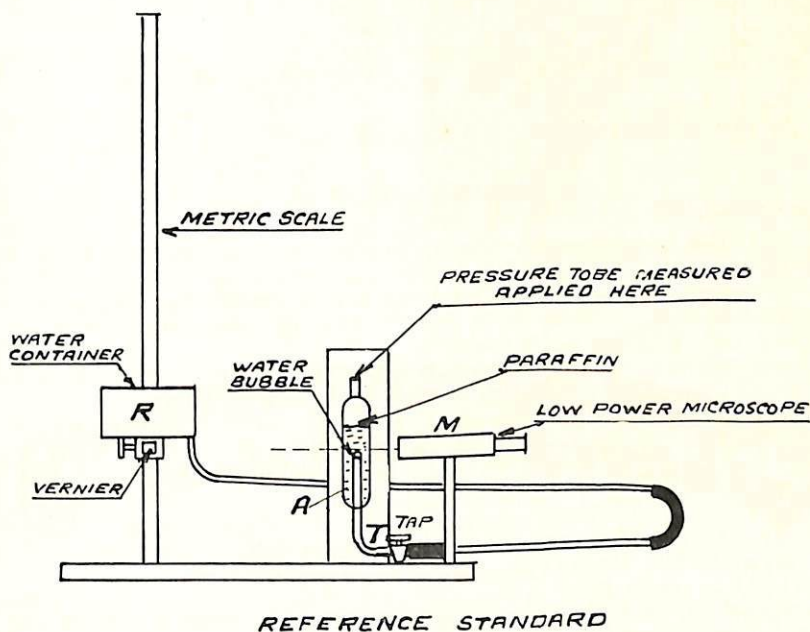


FIG. 32

The "Reference Standard" (Fig. 32) is essentially an elaborate form of U-tube manometer, used to measure a "head of water" very accurately. The water container is counterpoised and moves vertically against a specially calibrated metric scale. It is connected by flexible tubing to a fixed glass bulb, and the level of the water inside can be made to coincide with the axis of a low-power microscope, which is positioned in the horizontal plane containing the zero of the scale. A layer of paraffin prevents evaporation and renders it easier to observe the meniscus and take an accurate reading. In use, the position of the reservoir is adjusted until the head of water balances the pressure applied and the bubble meniscus appears on the axis of the microscope. The pressure is measured directly in terms of millimetres of water by the reading on the scale, which is provided with a vernier and can be read to an accuracy of 0.1 mm.

Pressure differences in millimetres of water corresponding to various speeds in miles per hour, are given in the following table.

Air Speed m.p.h.	Pressure difference mm. of water	Air Speed m.p.h.	Pressure Difference mm. of water
50	31.29	140	247.1
60	45.08	150	284.0
70	61.4	160	323.6
80	80.24	170	365.8
90	101.6	180	410.7
100	125.6	190	458.4
110	152.1	200	508.7
120	181.2	250	802.4
130	212.8	300	1166.0

The above figures are corrected for compressibility (see footnote p. 34).

6. INCLINOMETERS

The Cross Level

The Cross Level is used primarily to show the angle of inclination of the lateral axis of the aircraft to the horizontal.

The ordinary form of cross level is a curved glass tube mounted in a suitable aluminium frame with the convex outer side uppermost. The



FIG. 33. CROSS LEVEL (MARK IVA)
(Smith's Aircraft Instruments)

tube contains a non-freezing liquid enclosing a small bubble, which always tends to remain at the highest point of the tube owing to the fact that its density is small compared with that of the liquid. As the tube tilts when the aircraft banks, the bubble will move always so as to keep at the highest point. The displacement of the bubble from the centre therefore gives a measure of the tilt. There are fixed marks or points on

the frame showing the position of the centre of the bubble for angles of tilt of 10 and 20 degrees on each side of the vertical. Thus, the cross level indicates the angle at which the lateral axis of the machine is inclined to the horizontal in straight flight. It also serves as a banking indicator to inform the pilot when a turn is correctly banked. In this case the bubble will remain in the central position. In turning, therefore, the pilot watches the bubble and endeavours to keep it central by appropriate movements of the control column, thus avoiding side-slips. The control must always be moved in the direction of the bubble. Hence the rule: "Follow the bubble." This will be clear if the forces acting on the liquid are considered.

In straight flight, under the action of gravity the bubble will be central when the aircraft is flying level. The bubble will move to the right of the instrument if the left wing dips, and to the left if the right wing dips.

If the aircraft turns and the turn is correctly banked, centrifugal force comes into play and tends to keep the bubble central. If the turn is over-banked, the aircraft side-slips inwards in the direction of the resultant force. The result is that the bubble moves outwards. If the turn is under-banked, however, the aircraft side-slips outwards and the bubble moves inwards.

Two types of cross-level are used on civil aircraft. Mark Va has a blue band running along the back of the tube. Owing to refraction effects of the liquid, the blue band is not seen except just where the bubble happens to be, so that movements of the bubble are clearly seen against the white backing. A small electric lamp at one end of the frame serves to illuminate the bubble. This type is liable to burst if subjected to high temperature, and at low temperature the liquid may contract unduly, forming too large a bubble. Mark VII type is provided with an expansion bulb connected to the tube at one end by a short capillary. At normal temperature the tube is full of liquid, the bulb is about one-third full, and the bubble is about half an inch long. This type is specially used in tropical climates where wide ranges of temperature are experienced, and with the above proportions the size of the bubble remains fairly constant over a wide range of temperatures. If it is necessary to increase the size of the bubble, the instrument should be grasped by the lamp end and swung at arm's length with a quick circular movement. Some of the liquid will be driven into the expansion chamber. The size of the bubble may be decreased by grasping the tube by the other end and swinging as before.

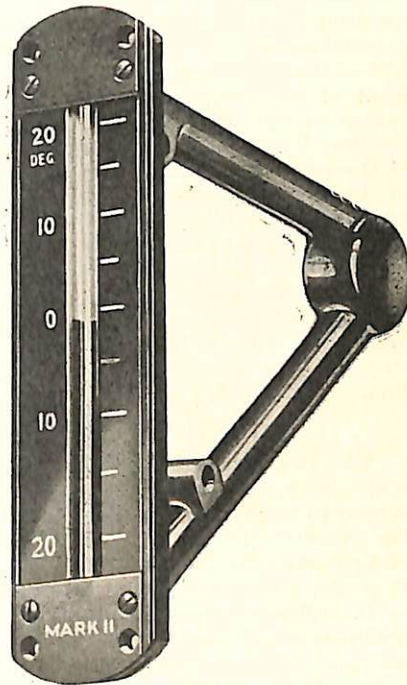


FIG. 34. FORE-AND-AFT LEVEL
(MARK IIa)

(Smith's Aircraft Instruments)

The instrument is mounted on the dashboard, so that the centre of the bubble is exactly opposite the zero mark when the aircraft is level and in flying attitude. It should be placed centrally and as nearly as possible on a level with the pilot's eye.

The Fore-and-aft Level

The Fore-and-aft Level is used to indicate the inclination of the longitudinal axis of the aircraft to the horizontal. It consists of a continuous closed glass tube of triangular shape fixed in an aluminium case, so that one side of the triangle can be seen through a slot in a scale plate fitted to the front of the instrument. A constriction in the lower limb damps out surges in the liquid. The glass tube contains a sufficient amount of coloured liquid to rise half-way up the exposed part of the tube and stand at the zero mark, when the aircraft is flying level. The tube is graduated in degrees both above and below the zero mark. During a climb the level of the liquid rises, and an indication of the tilt is given on the scale above the zero. During descent the liquid falls, and the inclination of the longitudinal axis of the aircraft is indicated in the part of the scale below the zero mark.

It should be noted that the instrument will give reliable indications of angles of climb (or dive), only when the aeroplane is climbing (or diving) steadily. The level of the liquid is affected by sudden changes in inclination, namely, during accelerated motion or the reverse.

7. HEIGHT INDICATORS OR ALTIMETERS

The altimeter is used to give an indication of the height of the aircraft above the ground level. The instrument in most general use is very similar in construction to the aneroid barometer, which actually measures the pressure of the atmosphere, that is, the pressure due to the weight of a column of air of unit area and whose height is that of the atmosphere. It is this pressure which is balanced by the pressure due to the mercury in an ordinary mercury barometer, and is usually expressed in inches or millimetres of mercury. The pressure is due to the weight of air above, and gradually decreases as the height above the earth's surface increases. If the air were always still and uniform in its composition and distribution, and not affected by any other influence but its own weight, the pressure due to the weight of the air would be an exact measure of the height above the surface of the earth. As these conditions do not hold, determination of accurate height is no easy matter. It necessitates exact knowledge of air temperatures and pressures at various heights. The average pressure at ground level is about 30 in. of mercury, or 14.75 lb. per sq. in., or 1,013 millibars. The meteorological unit of atmospheric pressure is the **Bar**, which is equal to a pressure of 1 megadyne per sq. cm. The millibar is a thousandth part of the bar, and is, therefore, equal to a pressure of 1,000 dynes per sq. cm. Its practical equivalent is 27 ft. of air at sea-level. The following conversion is a useful one to remember: Pressure due to 1 in. (or 25.4 mm.) of mercury (under standard conditions, namely at 0° C. and at mean sea-level in Latitude 45°) is equivalent to 33.9 millibars. Observations of pressure and temperature at various heights at different times of year have been recorded, and from them formulae have been evolved from which it is possible to calculate the height, approximately, from (1) a knowledge of the pressure at that height, (2) the pressure at ground level, and (3) the difference in temperature between these two points. Allowance is made for the temperature variation by adopting the I.C.A.N. convention of variation as explained in the

section on air speed indicators (p. 34). Both the I.C.A.N and Isothermal conventions, however, give only approximate results, but the I.C.A.N. convention more accurately represents average conditions all over the world. (See Appendix VI.)

The following table shows the height in feet, corresponding to barometer readings in inches, on both the Isothermal and I.C.A.N. conventions,

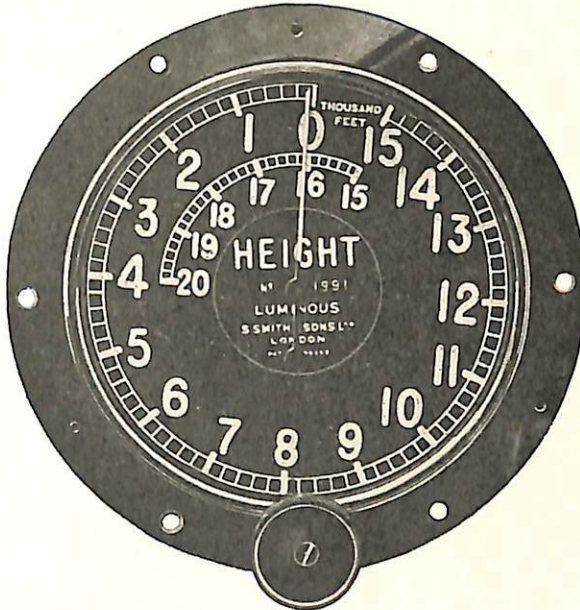


FIG. 35A. ALTIMETER (MARK V)
(Smith's Aircraft Instruments)

under standard conditions, namely at 0° C. and in Latitude 45° (29.92 in. = 760 mm.).

TABLE SHOWING HEIGHT IN FEET CORRESPONDING TO READINGS
OF THE BAROMETER IN INCHES

Height feet	Barometer Inches	
	Isothermal	I.C.A.N.
0	29.92	29.92
1,000	28.84	28.86
2,000	27.80	27.82
3,000	26.79	26.82
4,000	25.83	25.84
5,000	24.89	24.90
10,000	20.71	20.58
20,000	14.34	13.75
30,000	9.92	8.89

Before dealing with the calibration, however, a description of the instrument will be given.

The Instrument

The instrument is a barometer constructed on the aneroid principle, and contains a round, flat, metal box with corrugated sides, which is exhausted of air and sealed. In a very common type of construction (which, however, is becoming obsolete) one side of the box is fixed securely to the base plate, and the other side to a leaf-spring, which prevents the box collapsing under the atmospheric pressure outside it. Variations of air pressure, such as are experienced during a flight as the aircraft rises or falls, cause small movements of the side of the box attached to the leaf-spring. The movements of the spring and the box amount to not more than one-tenth of an inch, and, after magnification by a long, straight lever, and a bell-crank lever, are communicated to the pointer by a chain, arbor, and spindle. A hairspring is fitted to take up backlash and keep the chain taut. The dimensions of the parts are arranged so that the pointer moves over an evenly divided scale on the dial, and makes about one and a quarter revolutions. The dial, on which the heights are marked, can be rotated by means of a pinion (worked by a knurled head) meshing in teeth on the outer rim of the dial, and is set to read zero for sea-level before a flight. The height indicated during the flight will then be that above sea-level (not ground-level), provided that no change in the barometric pressure takes place during the flight. The instrument is compensated for temperature changes at ground pressure only by a compound brass-steel connecting link incorporated in the mechanism. Owing to unequal expansion of the two metals this link assumes a curved shape if the temperature is varied. Its effective length is unaltered and the readings consequently unaffected. This compensation will be referred to later when errors of altimeters are dealt with. In order that the instrument may respond to changes of pressure, the case of the instrument is *not* airtight, and in some types of altimeters is provided with a small hole open to the atmosphere.

The following types of altimeter are approved for civil aircraft—

Mark V	.	.	.	Range	16,000 ft. by 100 ft.
Mark Va	.	.	.	"	20,000 ft. by 200 ft.
Mark Vb	.	.	.	"	26-28,000 ft. by 100 ft.
Pioneer No. 355	.	.	.	"	20,000 ft. by 200 ft.

Civil Instrument Specification No. 1 (see p. 120) lays down the minimum requirements.

The K.B.B.-Kollsman Sensitive Altimeter

This instrument (Fig. 35B) is actuated by an aneroid unit fitted with a geared mechanism which moves three pointers of different lengths over a common scale. The longest pointer completes one revolution for every 1,000 ft. change of altitude and the scale is graduated in hundreds of feet. Another smaller pointer indicates the number of revolutions of the largest pointer and therefore thousands of feet. A still smaller pointer indicates tens of thousands of feet. The widely spaced graduations enable small differences of altitude to be observed, a difference of 5 ft., one-quarter of a scale division being immediately apparent. Lag is reduced to such an extent that the pointers return to zero, within less than 10 ft. after a descent from 10,000 ft. at the average rate of 1,000 ft. per minute. Provision is made for connecting the case of the instrument to the static line of the air speed indicator to avoid errors due to differences between the pressures in the cockpit and the external pressure. Temperature compensation is such that at low altitudes, the error due to temperature

amounts to a fraction of a foot. Thus the instrument is suitable for use as a landing altimeter. Adjustment for variation in atmospheric pressure is made by rotating a knob at the lowest part of the instrument case. This causes rotation of a short scale of millibars (or inches) visible through a small aperture in the dial. The scale can thus be set to a fixed reference mark. Any slight change in the zero due to slow release of internal stresses in the diaphragm can be detected by setting the pointer to zero and comparing the reading of the auxiliary barometer scale with that of the standard barometer. By loosening the zero-setting screw (seen just to the left



FIG. 35B. K.B.B.-KOLLSMAN SENSITIVE ALTIMETER

of the knob in Fig. 35B) the knob can be pulled outward and turned so as to move the barometer scale only, until the reading corresponds to that of the standard barometer. The knob is then pushed home and the setting screw replaced.

Errors of Altimeters

The aneroid barometer, or altimeter, may undergo considerable changes occupying in some cases quite long periods of time. These changes are, however, dependent on the type of instrument, and the care and attention paid to its design and construction. This must not be taken as an indication that the altimeter is generally an erratic and unreliable instrument, as although there are many errors which are variable in character, these errors in a good instrument can be attributed to definite physical laws, and consequently very close allowances and corrections for them can be made.

Altimeter errors can be briefly classified as follows—

(a) Errors due to the instrument not being in a physically stable state. These can be avoided by waiting long enough before readings are taken.

(b) Errors due to changes taking place over a considerable period. These are due to the gradual settling of the parts as is frequently found with instruments manufactured hurriedly and put into service before a reasonable ageing period has been allowed. These errors need not be serious if the instruments are checked against reliable standards from time to time, and adjusted as necessary.

(c) Inherent errors, due to faulty or imperfect design or construction, and due to the physical properties of the materials used in construction.

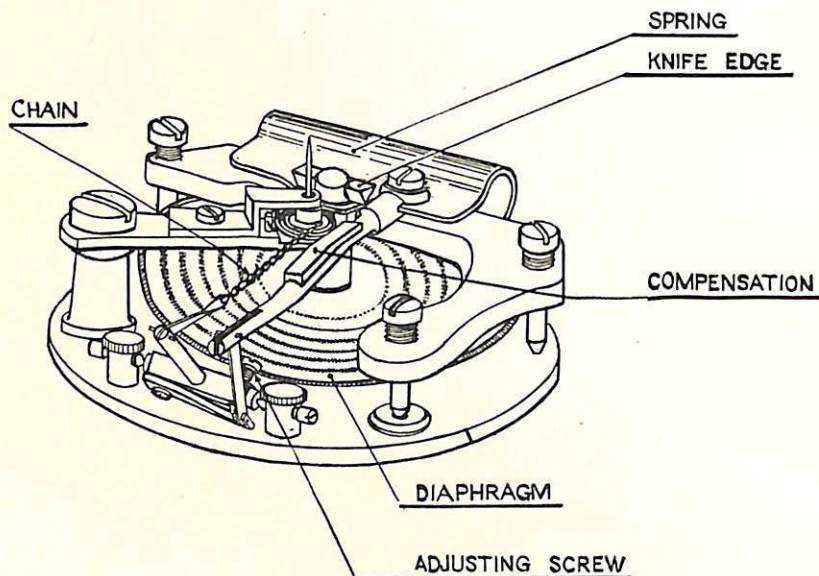


FIG. 36. DIAGRAM OF ALTIMETER MOVEMENT

Under this heading may be included temperature errors and the effect of temperature on the elasticity of the diaphragm and spring. An attempt is made at compensation by the incorporation of the bimetallic arm previously described, but this chiefly affects changes in temperature at ground pressure, and does not allow for changes in stiffness of the elastic system under low pressure conditions. Among the inherent mechanical errors are those due to friction or backlash in the moving parts (e.g. the linkwork), and lack of balance of the moving parts. These errors can be reduced to a minimum in service by using the instrument in the same position in which it has been tested, and by tapping the instrument lightly during testing. (Tapping should not be more violent than the equivalent of normal aircraft vibration.) Further errors result from the imperfect elasticity of the spring and diaphragm combination, resulting in (a) "Creep," or the gradual increase of reading which takes place when an instrument is maintained in a constant low pressure condition for several hours, and (b) Hysteresis, or "Lag," which is the excess of the "down" readings (taken as the pressure is increasing) over the "up" readings (taken as the pressure is decreasing). (See p. 48.)

This type of altimeter has been described and its sources of error fully discussed since it is the type which the ground engineer is most likely to meet with in the course of his work.

Of recent years great improvements have been made in the design of altimeters, resulting in reduction of lag; at the same time automatic compensation is made for errors due to the effect of change of temperature upon the elasticity of the spring and diaphragm at different altitudes. In these instruments the diaphragm boxes are constructed of selected material which is subjected to special treatment as described in the section on Air Speed Indicators (p. 33). They are evacuated to a pressure approximately that of $\frac{1}{4}$ mm. of mercury. A better method of supporting the spring has

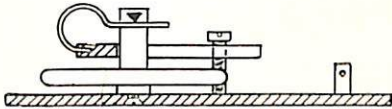


FIG. 36A

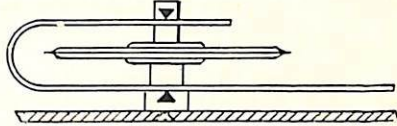


FIG. 36B

been introduced (see Fig. 36B) and the diaphragm box is supported entirely on knife edges. The older method of mounting is shown in Fig. 36A for comparison.

In modern instruments, compensation for errors due to change of temperature is effected by fitting a compensating helix to the pointer. The helix is made of "invar" steel and brass, and is so constructed that a rise in temperature causes it to coil more tightly owing to the greater coefficient of brass as compared with that of steel. Thus the pointer spindle is turned in a clockwise direction and counteracts the movement in the opposite direction due to the contraction of the spring.

Installation

The altimeter should be fitted to the instrument panel with the dial in a vertical plane, and the adjusting knob at the bottom of the instrument. If it is mounted in an horizontal position, its errors and behaviour should be known in this position, or inaccuracies may be introduced, and the effect of vibration may be increased. The adjusting knob should work smoothly. No attempt should be made to force it, or the teeth may be stripped from the pinion of the spindle. Repairs to the instrument should only be carried out by a trained instrument mechanic. If the pointer is not in the approximately vertical position in the types of instruments mentioned above, the accuracy should be suspected. The instrument has probably been dropped or received some sort of jar.

Mention has been made of the fact that the case should not be airtight. A small hole may be drilled in the instrument case allowing the instrument to record the external pressure. Altimeters in enclosed compartments are subject to errors due to difference between the pressure inside the compartment and that of the pressure of undisturbed air outside. This difference of pressure (which may cause an error amounting to as much as 150 ft.) may be observed during flight by a movement of the pointer, when a window in the neighbourhood of the instrument is suddenly opened. The error increases as the speed of the aircraft increases and decreases slightly as the height increases. To reduce this error, altimeters are often fitted with an airtight case connected to the static side of the air speed indicator installation. It is essential that the altimeter case as

well as the connections to the static side should be free from leaks in order to ensure that no serious error is produced in the reading of the air speed indicator. The usual tests for leaks should be applied after connecting up to the case of the instrument. No leak is permissible on the pressure side, and the leak, if any, on the static side should not be greater than that indicated by a movement of the pointer from the 150 m.p.h. mark to the 135 m.p.h. mark in 10 seconds.

Tests on Altimeters

In some altimeters a lubber mark is painted on the bezel plate to indicate the position of the pointer at standard barometric pressure. The letters S.B.P. are painted alongside the mark, which serves as a zero and is useful when taking off from aerodromes in elevated and tropical localities.

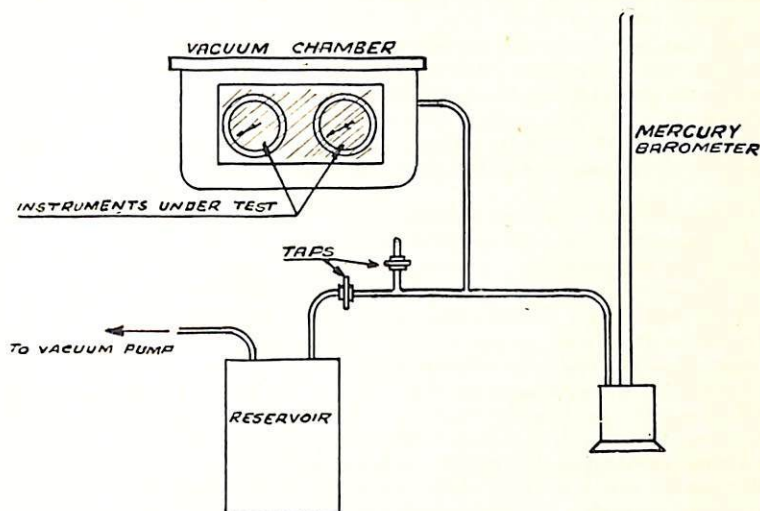
A test on the accuracy is made by placing the instrument in a chamber from which the air can be exhausted gradually by means of a suitable pump. A capacity reservoir is introduced to prevent sudden changes of pressure, and an accurate mercury barometer is connected to the vacuum chamber to show the pressure at any instant. The barometer is conveniently provided with scales, inches of mercury on one side and equivalent thousands of feet on the other. In many types, owing to lag errors, after a rapid descent from, say, 20,000 ft. the pointer may indicate 300 ft. instead of zero. After a minute or two this may reduce to 100 ft., but an hour or two at least must elapse before the pointer returns to zero. For this reason, tests are usually made at the standard rate equivalent to a rise or fall of 1,000 ft. per min. in one continuous test. Under these conditions the permissible errors vary according to the particular point of the range. The following figures are approximate—

PERMISSIBLE ERRORS FOR ALTIMETERS

	0/28,000 ft.		0/20,000 ft.		0/16,000 ft.	
	Up	Down	Up	Down	Up	Down
0	0	+ 225	0	150	0	150
1,000	- 60	+ 270	- 40	+ 160	- 40	+ 160
2,000	- 90	+ 310	- 60	+ 180	- 60	+ 180
3,000	- 120	+ 350	- 70	+ 190	- 70	+ 190
4,000	- 140	+ 370	- 80	+ 200	- 80	+ 200
5,000	- 150	+ 400	- 80	+ 230	- 80	+ 230
6,000	- 160	+ 420	- 90	+ 250	- 90	+ 250
7,000	- 170	+ 440	- 100	+ 280	- 100	+ 280
8,000	- 180	+ 460	- 110	+ 300	- 110	+ 300
9,000	- 190	+ 480	- 110	+ 320	- 110	+ 320
10,000	- 200	+ 490	- 110	+ 330	- 110	+ 330
15,000	- 240	+ 510	- 140	+ 400	- 140	+ 400
16,000	- 250	+ 510	- 150	+ 400	- 150	+ 400
20,000	- 300	+ 490	- 200	+ 400		
25,000	- 390	+ 420				
28,000	- 500	+ 350				

A mercury barometer will remain accurate for a considerable period, but an error is gradually introduced by the very gradual in-leakage of

air in the mercury. A test for air in the vacuum space above the surface of the mercury at the top of the column may be made in the following way. The whole tube is gradually inclined away from the vertical. If no air is present, the mercury will completely fill the space, coming against



ALTIMETER TESTS

FIG. 37

the top of the glass tube with a metallic "click." If air is present, it will act as a cushion for the mercury, and a small bubble of air may be observed if the top of the glass tube is visible. Great care should be taken not to incline the barometer too suddenly, or the mercury may rush to the top of the tube and cause fracture. If air is present, the barometer should be returned to the makers for overhaul.

Check Against a Sub-standard Altimeter

If a small vacuum chamber and an exhaust pump are available, the altimeter may be checked against a sub-standard by placing both instruments in the chamber and exhausting the air. (See Fig. 37.) The readings at various points of the scale may then be compared. In making these comparisons, the corrections (supplied with sub-standard instruments) must be applied. The rate of change of pressure, whether increasing or decreasing, should not exceed 1,000 ft. per minute.

Testing of Altimeters

Altimeters of the rotatable dial type are usually tested not only over the range marked on the dial but over the whole range of pointer movement which may be experienced in actual use. This complicates the test in a way which must now be discussed.

Tests are conveniently carried out by means of a standard mercury column calibrated in inches of mercury as well as in equivalent heights according to the isothermal or I.C.A.N. conventions.

Consider a reliable instrument, which has been set to read zero at sea-level when the barometric pressure is the standard pressure of 29.99 in. (London Laboratory Conditions.) (See p. 96.) Provided the barometric pressure remains at this value during a flight, the instrument will give the height above sea-level, assuming that the various sources of error are left out of account.

The barometric pressure, however, is seldom equal to the standard pressure. If the barometer is "high" on the occasion of some subsequent observation at sea-level, the pointer shows a reading below the zero of the scale: if "low," above zero. This is equivalent to a shift of the whole scale in one direction or the other. It is therefore desirable to test the instrument at pressures slightly above and below the normal range of the scale.

One method of test is as follows—

The reading of the barometer at the time of test is taken from the height scale and noted in terms of feet. Let us suppose it is ± 160 ft.

(The plus sign indicates a reading in the positive direction on the Isothermal scale of feet, and corresponds to a change of barometric pressure from the normal of 29.99 in. to *below* normal, namely, to a reduction in atmospheric pressure.)

The dial is then rotated until the pointer stands opposite a reading of 160 ft. *above* the arbitrarily chosen mark of 1,000 ft.—namely, at 1,160 ft. (The 1,000 ft. mark is conveniently chosen instead of 0, since the scale is not always marked on the negative side of the zero.)

The instrument is then placed in the test chamber and the pressure gradually *increased*, corresponding to a "rising" barometer, until the standard mercury column reads $-1,000$ ft.

If the instrument has been correctly made and adjusted, the pointer should then indicate zero, since it was previously set to compensate for the difference between the barometer reading and the standard of 29.99 in.

The pressure in the test chamber is then gradually *reduced* (at a rate equivalent to an ascent of 1,000 ft. per minute). Readings are taken at convenient multiples of 1,000 ft. up to 1,000 ft. greater than the maximum range. Down readings are then taken at the same rate and both up and down readings are tabulated.

It will probably be found that there is an error at the zero of the scale of Isothermal heights (i.e. at 29.99 in. of mercury). In this case, the readings at 0 ft. and above must be "corrected for zero error" by adding algebraically, such a figure as will reduce the error at zero to nil. Thus, if the error at zero is -30 ft., $+30$ ft. must be added to each reading.

After correcting for zero error in this way, the figures are compared with those given in the Table of Permissible Errors.

It should be noted that the true readings are all 1,000 ft. above the apparent readings, since the instrument was originally set at 1,000 ft. instead of zero, in order that negative readings might be taken. There should be no confusion, however, if the observed errors are set down in the spaces opposite the true markings.

The reader should consider carefully the reason for the "correction for zero error" referred to above. The error at zero is mainly caused by the test to $-1,000$ ft., and if the instrument is allowed to rest and recover, most of this error at zero will disappear. If the error is not excessive, it may be assumed that the altimeter can safely be used starting at $-1,000$ ft. (as when the barometer is "high"). Being satisfied as to this, we proceed

to consider the behaviour of the instrument when a further test is made, starting from the more usual barometric pressure, namely, 29.99 in. of mercury. In order to continue the tests without the delay involved in allowing time for the instrument to recover, the "correction for zero error" is made.

In reality, the method described above involves two separate tests: (a) a test on the behaviour of the instrument during a climb from ground level when the barometer is "high," namely, from the equivalent - 1,000 ft. and (b) a test on the behaviour of the instrument during a climb starting from ground level, when the barometer stands at 29.99 in. It is emphasized that the Table of Permissible Errors assumes the conditions of test (b). The correction for zero error ensures that test (a) shall not have any influence on test (b).

The use of the Isothermal and I.C.A.N. scales usually presents difficulty and is dealt with more fully in Appendix VI, p. 96.

Limitations of the Aneroid

It is desirable to emphasize the limitations of the aneroid as a height measurer.

Even if an instrument has been checked and found to be within the allowable limits of calibration, and the calibration is stable, it should be appreciated that—

1. It is calibrated for average conditions of atmospheric pressure and is subject to errors when used under any other or abnormal conditions.

2. If set for zero at sea-level before a flight it will only give reasonably accurate readings during steady flight, provided that no change in atmospheric pressure (evidenced by a change in the "height of the barometer") has taken place since the start.

3. It is subject to "cockpit error" (see p. 47).

4. During a change of height—rise or fall—it is subject to lag errors (see p. 48).

5. On landing, the height indicated will be that above sea-level and not zero—leaving the various sources of error out of account.

If these limitations are realized and allowed for when necessary, the aneroid will still prove to be a useful instrument. The advantage of an instrument giving an instantaneous reading of height above ground or sea level at any instant during a flight is obvious, but unfortunately, up to the present no such instrument has been devised. It is quite impracticable to measure the height directly and an indirect method must therefore be used. The pressure-difference method at present in use suffers from the disadvantages mentioned above. Alternative methods based on Electrical Capacity or Sound Echo principles have so far proved disappointing.

8. WATCHES¹

For watches to be carried under the Air Navigation Directions, any make of watch of good commercial quality is accepted. The following notes are of general interest.

The driving power of a watch is derived from the mainspring which operates through a train of wheels, and is released at an even rate by the escapement, which is, as it were, the "heart" of the watch. The balance wheel and hairspring control the movements of the escapement. The

¹ For further information the reader is referred to *Modern Watch Repairing and Adjusting* (N.A.G. Press, 26 Old Street, E.C., price 4s.).

balance wheel of a watch kept continuously running vibrates about 150,000,000 times in the course of twelve months, and at the end of six months or so the oil in the movement commences to deteriorate. It is essential, therefore, for efficient running and time-keeping, that a watch should be cleaned and re-oiled at intervals of from 12 to 18 months.

The Mainspring

Breakage of the mainspring is one of the most frequent causes of failure. A broken mainspring is easily detected from the fact that the winding button turns easily and is inoperative.

The spring is a piece of tempered steel approximately 18 in. to 22 in. in length, coiled and housed in a barrel between the upper and lower plates of the movement. The strength and dimensions depend on the particular type of watch. The most common cause of breakage is overwinding, but the design is often such as to render this impossible.

The condition of the mainspring is continually varying from maximum tension when fully wound to minimum tension when the watch has run down. It is also subject to extreme changes of temperature, ageing, and deterioration. These conditions are outside the control of the user and occasionally result in failure.

The Balance Staff

The balance staff is the shaft on which the balance wheel rotates. It is provided at each end with a very fine pivot in order to reduce friction to a minimum. The pivots rotate in jewelled holes, and, being delicate, will bend or break with the greatest ease if the watch is subjected to rough treatment. A breakage will result in the balance wheel stopping. A bent pivot causes unevenness of motion to be imparted to the balance wheel, resulting in bad time-keeping or intermittent running.

Jewels

In every well-constructed watch of the lever escapement type there should be at least seven jewels. The balance wheel unit should have two jewels at each end—a jewel-hole and an end-jewel. Periodically the balance wheel staff is in contact with a fork piece with two branches at the other end. These are known as pallets, and they permit the release of the escape wheel alternately. Each pallet has a jewel. The seventh jewel is in the balance and engages with the fork. In a fifteen-jewel movement, eight more jewels are provided for the pivots of the pallet staff, the escape wheel, and the third and fourth wheels.

Trouble may be caused by badly fitting or cracked jewels, the refitting of which calls for considerable skill and experience and should only be undertaken by an experienced watchmaker.

Balance and Hairspring

The balance and hairspring are very important parts of a watch, and it is chiefly these parts which distinguish a good watch from an inferior one. In almost all watches, except those of low grade, the balance wheel consists of bimetallic segments of brass and steel, constituting the rim. A number of small screws (in the rim) weight and poise the balance according to the strength of the hairspring. The rating adjustments are made in the balance wheel and hairspring. The performance is usually expressed as a "rate," and a watch may have a gaining rate or a losing rate. The balance wheel controls the action of the escapement and oscillates about

three-quarters of a revolution in each direction. The wheel needs control and this is the function of the hairspring. Hairsprings are usually either of the flat or of the Breguet (or overcoil) type. The former is a simple flat coil spring. In the latter type (named after Breguet, an early watchmaker who first applied the principle) the outer coil is diverted from the true spiral, and the end is brought over the inner coils to its anchorage. This design is an attempt to allow free expansion and contraction of the spring in all directions, and reduces unevenness and side-friction on the pivots, and obviates the effect of position errors on an unbalanced hairspring.

Watches should be adjusted for time-keeping under conditions of temperature and position. Temperature adjustments are made in the

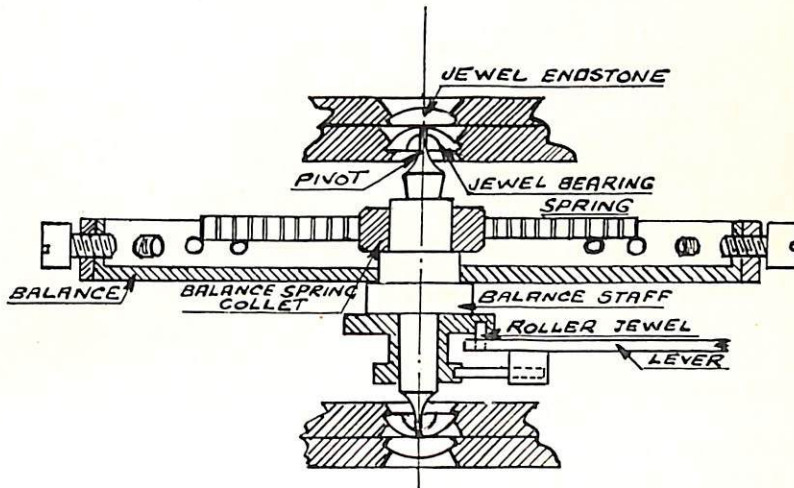


FIG. 38. SECTIONAL DIAGRAM OF WATCH BALANCE

balance wheel. Position adjustments are effected by the correct adjustment of the whole balance assembly—hairspring and escapement.

Magnetism

Occasionally, erratic time-keeping can be traced to the hairspring having become magnetized. It can be cured by suspending the watch by a twisted cord near a powerful magnet, and allowing the cord to unwind and rotate the watch, which is gradually withdrawn from the neighbourhood of the magnet while still rotating.

The Hands

Unless the hands of a watch are carefully fitted, they may touch one another or the dial or glass during their revolutions and cause the watch to stop. "Unbreakable glasses" of a celluloid compound are now often fitted and, being relatively soft, may be pressed down in contact with the hands and bend them out of position. It is advisable, therefore, to test by drawing the winding stem into the "set hands" position and carefully rotate the hands, while watching closely the clearance between the dial, the glass, and the hands. Adjustments can be made with a pair of tweezers.

Timing

The 30-hour watch should not gain or lose more than 30 sec. in a 24-hours' run. Tests should be made in three consecutive days in the position in which the pendant is uppermost. The balance poise can be checked by timing when the pendant is 30 degrees on either side of the vertical.

9. TURN INDICATORS AND BANK INDICATORS

The turn indicator is used primarily for indicating deviations from a straight horizontal course. When flying in cloud or fog, in the absence of some external point of reference, and when there is no visible horizon to

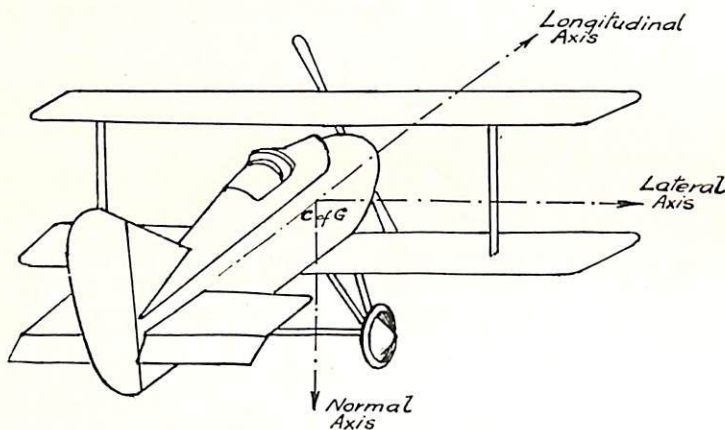


FIG. 39. THE AXES OF THE AEROPLANE

act as a guide, it is practically impossible for the pilot to keep the machine on a straight course. Without realizing it, the pilot may be flying in a sharp curve, and it has even happened that, on emerging from a cloud, the pilot has found that he was flying upside down.

If the angle of bank is large, the pilot may realize from his muscular reactions that he is not on a straight course, but he cannot tell whether he is in a right-hand or a left-hand turn. If he attempts to straighten his course, he is quite likely to make incorrect movements of the controls and increase the curvature instead of reducing it. The compass is no guide to him in these conditions as the readings are unreliable when the speed of the aeroplane is changing or during a turning movement (see p. 68).

An essential requirement is therefore a turn indicator—an instrument which indicates, under all conditions, whether the path of the aeroplane is a straight line or whether it is turning to right or to left. The instrument not only enables the pilot to keep a straight course but, at the same time, affords valuable information of the rate of turn either to right or left, as well as of the correctness of his banking. The general effect on the machine of incorrect banking has already been considered in the section on cross-levels.

The Axes of an Aeroplane

The movements of an aeroplane in normal flight are usually referred to a system of three mutually perpendicular axes, fixed in the aircraft and moving with it.

These axes all pass through the centre of gravity and their positions will be clear from the diagram.

The following table shows the effect of a turn about each axis, names the control producing the turn, and mentions one instrument in each case which may serve to indicate the turn.

Axis of turn	Control	Movement	Indicating Instrument
Longitudinal	Ailerons	Roll or bank	Cross Level
Lateral	Elevator	Pitch	Fore and Aft Level
Normal	Rudder	Yaw	Compass

Most of the types of turn indicator in general use are proprietary, and the makers give full instructions for installing and maintaining their instruments in proper working condition. These instructions should be carefully studied, as successful performance depends very largely on closely following them. If a fault develops it is seldom possible to correct it, and, therefore, in this case, the wise course is to return the instrument to the makers for overhaul and adjustment.

Several types have been approved for use in civil aircraft. The minimum requirements are laid down in Civil Instrument Specification No. 8 (see p. 130). See also Civil Specification No. 14 (Directional Gyro).

The Venturi Tube

Many Turn Indicators are operated by the suction produced by a Venturi tube, acting on the same principle as the injector on steam engines.

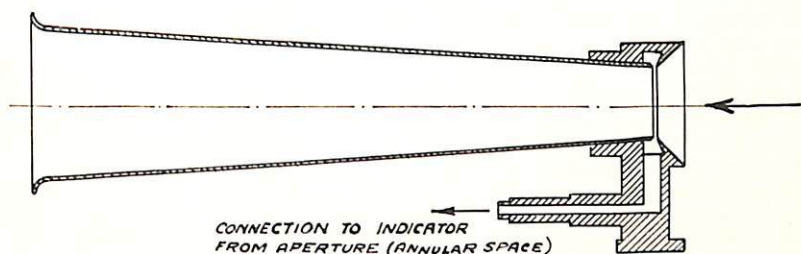


FIG. 40. DIAGRAM OF VENTURI TUBE (REID-SIGRIST)

The Venturi is a tapered tube open at both ends, placed in an air stream. The flow of air through the tube causes a reduction of pressure at a side aperture which is connected by tubing to the airtight case of the indicator. The suction created by the reduced pressure causes air to be drawn from the exterior of the indicator case through a jet, which impinges on the grooved periphery of the rotating wheel constituting the gyro. In this way the rotation of the wheel is maintained.

The advantage of fitting the Venturi in the slip stream is that the instrument is caused to operate from the moment the airscrew is set in motion. Thus, indications are given from the start of a flight—an important consideration in foggy weather.

Turn indicators driven by Venturis can be simply constructed and made

mechanically reliable. Owing to the exposed position of the Venturi and the cooling effect of the air flow, there is liability of blockage due to the formation of snow and ice at low temperatures. To avoid this trouble in some American types, the Venturis are electrically heated.

Electrically driven turn indicators are not subject to these troubles and can be conveniently designed to give indications by illuminated coloured screens. As the instrument serves as an auxiliary to the compass, it is usual to group the two instruments near to one another, and therefore freedom from interference with the compass is an important feature of the design which must be carefully considered. Regular maintenance also is important to ensure satisfactory service.

The Reid Control Indicator

The Reid Control Indicator combines three functions in one instrument, giving indications of the movement of the machine in three directions. An air speed indicator is fitted centrally, giving readings of movement in the fore-and-aft direction. If the nose of the machine moves downward, an increase of speed will be indicated. If the nose moves upward, the pointer will show a corresponding decrease of speed.

Indications of turn to right and left, and of tilt in a transverse direction, are given by systems of small electric lamps. If the aircraft turns about its longitudinal axis, mercury in a U-shaped glass tube, mounted parallel to the front of the instrument case, moves under gravity and makes electrical contacts (by wires fused into the glass), causing one or more of the series of "aileron" lamps to light up. The lamps are arranged round the upper half of the air speed indicator case, and, by observing them, the pilot knows how to use his aileron control in order to correct the displacement and restore the machine to normal flying position. The arrangement acts as a bubble level. A lower row of horizontal lights (controlled by a small gyro, with its axis set in the horizontal plane of the aircraft) gives indications for rudder control. The gyro rotates at about 5,000 r.p.m., and is actuated by a small Venturi. Its movements, relative to the frame, cause electrical contacts to be made by insulated flat springs in circuit with the series of lamps. The pilot manipulates the rudder control so as to keep the centre lamp only illuminated.

Care should be taken in installing the instrument, and the detailed instructions for fitting should be carefully followed. The indicator must be squarely fitted when the aircraft is trimmed on a level keel. The best method is to tilt the instrument case first to one side, then to the other, and to mark the position when the first lamp in each case lights up. The half-way position is correct.

The gyro unit is fixed by means of a split clamp ring and must be fitted so that the axis of the gyro is in the horizontal plane. The control taps should be placed within easy reach of the pilot. It is best to fit the Venturi in the slip-stream of the propeller, where there is a good unobstructed flow of air.

The following types of Turn Indicator incorporate a gyroscope. The reader is referred to Appendix VII (p. 101) for further details.

The Pioneer Turn Indicator

The Pioneer type of turn indicator utilizes a small air-driven gyroscope operated by a Venturi. The indicator is mounted on the instrument panel with the dial vertical, so that the ball is in the centre of the cross-level tube (incorporated in the dial) when the aircraft is in normal flying attitude. Connexion to the Venturi is made by a suitable

length of $\frac{1}{4}$ -in. copper or brass tube, which should have as few bends as possible. The cones of the connecting unions should be soldered to the tube, care being taken to avoid any of the solder running on to the cone seating. Coupling nuts are provided for tightening up the joints. The Venturi should be mounted with the "arrow" pointing forward, on the side of the fuselage or on a strut, preferably in the slip-stream so as to receive an unobstructed current of air.

The Venturi must be examined periodically for freedom from obstruction or dirt, and the nuts tested occasionally for tightness. At the back of the instrument there is a jet screen, which can be removed by unscrewing the knurled retaining nut. The screen should be cleaned after 100 hours' flying time. The only place where oiling is necessary is the screw hole on the right-hand side of the instrument case. Six drops of oil of good quality should be used for the purpose after every 300 hours' flying.

The Schilovsky-Cooke Turn Indicator

The Schilovsky-Cooke Turn Indicator employs a slow-speed, direct-current electric motor, acting as a gyro. The motor is mounted with its axis athwart the aircraft, and the axle is carried in a gimbal ring pivoted at its front and rear ends on knife edges. It is also weighted so that the axis of the gyro is horizontal when the gyro is not rotating. The gyro is run from a 12-volt battery, and turns at a rate of about 1,200 r.p.m. The axis of the gyro in motion tends to preserve its direction in space. When the aircraft turns, a transparent coloured screen attached to the gimbal ring moves across a window at the top of the instrument case, giving indications of the direction and the amount of the turn by exposing green or red bands of light from a small lamp at the back. The gyro element on its knife-edge bearings constitutes a long period compound pendulum with slight gravitational control. On switching on the current by the lever provided, the gimbal frame is deflected momentarily so that it swings freely and comes to rest in the correct position. On switching off, the whole gimbal frame assembly is automatically clamped to prevent damage by vibration. The instrument embodies a mechanical pendulum, which serves as a cross-level device, giving indications by means of the movements of a "bubble," illuminated so as to appear as a bubble of white light.

Tests on the sensitivity of the instrument are made on a turntable, which can be caused to rotate at constant measured speeds. The instrument should show the same deflections on each side of the vertical for each speed for either direction of rotation. The following is the usual scale of sensitivity—

1 turn per 15 min.	.	.	Deflection not less than	5°
1 " 7 $\frac{1}{2}$ "	.	.	" " more "	10°
1 " 7 $\frac{1}{2}$ "	.	.	" " less "	10°
1 " 4 "	.	.	" " less "	17 $\frac{1}{2}$ °

A scale of spots corresponding to the above deflections is provided just above the window, for convenience during the test.

Both the gyro movement and the cross-level are provided with independent air dash-pots to reduce the oscillation of the mechanism. Control of the "damping" is effected by manipulating knurled knobs at the bottom of the instrument case. The final adjustments to suit the particular aircraft are made in the air during a trial flight. The damping adjustment does not affect the sensitivity, but is necessary in order to avoid undue lag or too rapid movement of the coloured screens. A given

rate of turn will always produce the same deflection, either quickly or slowly, according to the adjustment of the damping. The illumination is controlled by a dimming switch which limits the amount of current passing to a value between 0.6 and 0.8 amp.

The installation must be carefully carried out. The instrument must be mounted on the instrument panel in full view of the pilot and as far from the compass as possible, owing to the mass of iron used in the construction. The minimum permissible distance is 4 in. between the edges of the two instruments.

The compass may show a momentary deflection at the moment the switch is operated either to the "on" or "off" position, but the permanent effect is negligible. Adjustment of the compass must be made after the turn indicator has been fitted. The indicator is fitted by spring bolts provided with nuts and washers, and the upper part is retained in position by a spring clip which permits of the instrument being tilted forward through a small angle—sufficiently far to enable the cover of the lamp recess at the back to be removed and the lamp changed, should this be necessary. The retaining clip must therefore be mounted a little to the left or right of the vertical central line to enable this to be achieved.

The student will find it to his advantage to consider the various positions of the pointer and the bubble under different conditions of flight. Reference should be made to the section on cross-levels, where the causes of the movements of the bubble are discussed.

The Reid-Sigrist Turn Indicator

The Reid-Sigrist Turn Indicator embodies a gyroscope, driven by a Venturi, and a cross-level indicating device. The gyro is mounted in an horizontal gimbal ring of which the axis is in a fore-and-aft direction, the gyro axis being in a transverse direction. Any tendency of the aircraft to turn off its course applies a torque to the gyro. This torque produces precessional motion causing the gimbal ring to rotate about its fore and aft axis. If this movement were uncontrolled the gimbal ring would continue to rotate until it had moved through 90°. It is, however, controlled by a spring, the tension in which balances the precessional torque. A toothed quadrant fixed to the gimbal ring operates a simple damping mechanism, consisting of a small piston driven by a geared-up crank and working in a cylinder. The movements of the gimbal are communicated to the pointer by a two-to-one magnifying mechanism. The sensitivity of the instrument is controlled by a spiral spring, the tension in which can be adjusted by a screw, accessible through a hole in the case; the hole is normally closed by a screwed plug.

The instrument indicates the *rate of turn*, namely, the ratio between the number of degrees turned through, and the time taken. Thus, there is a quick response at the commencement of the turn, and the pilot can immediately make the necessary corrective movements of the control before the movement becomes excessive. The indications of the "rate of turn" pointer are not affected by the attitude of the aircraft, and are the same if the machine is flying upside-down. The pointer moves always in the direction to which the nose of the aircraft is moving, and the angle it assumes shows the rate of turn (or yaw) of the machine.

The cross-level indicator takes the form of a pendulum fitted in a little box of triangular section placed just behind the dial. The clearance between the plate pendulum and the sides of the box is very small, and provides suitable damping. The movements of the pendulum are communicated to the pointer (working over the upper part of the dial) by

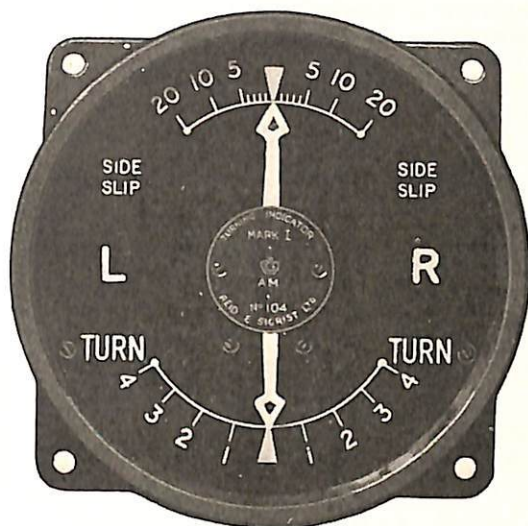


FIG. 41. "REID-SIGRIST" TURN INDICATOR

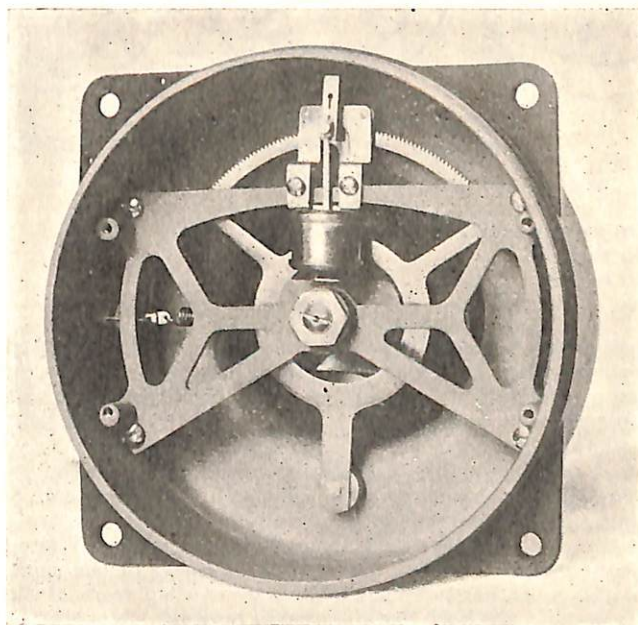
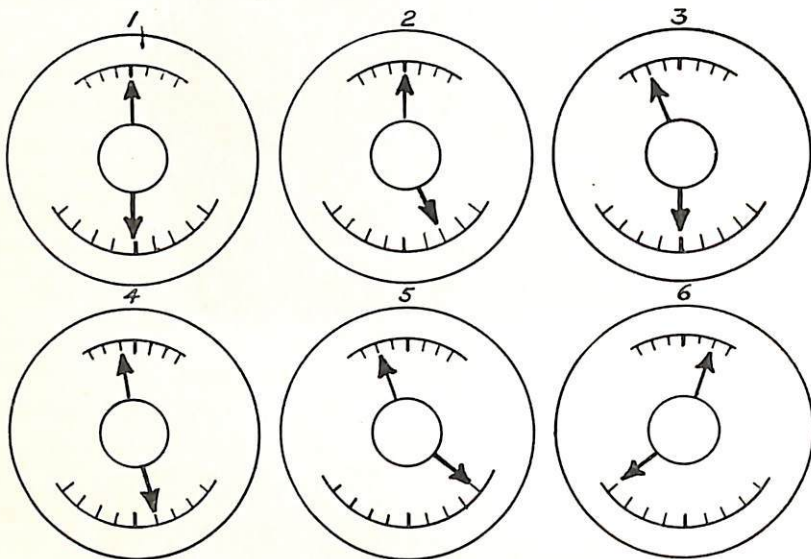


FIG. 42. "REID-SIGRIST" TURN INDICATOR. (INTERIOR VIEW SHOWING DAMPING MECHANISM AND SENSITIVITY CONTROL SPRING)

mechanism which gives large indications for small angles of tilt—the magnification is approximately 5 to 1 at the zero, which makes it possible to fly within $\frac{1}{2}$ degree of lateral level.

The examples of instrument indication illustrated should be studied—

1. Straight flight.
2. Turn to right. Banking correct.
3. No turn. Side-slip to left.



*REID-SIGRIST TURN INDICATOR
EXAMPLES OF INSTRUMENT INDICATIONS*

FIG. 43

4. Turn to right. Slight side-slip to left.
5. Spin to right.
6. Spin to left.

Tests

The instrument is tested with the dial in a vertical plane, and with an air suction equivalent to 3 in. of mercury. The gyro must commence to rotate with a reduction in pressure of $\frac{1}{4}$ in. of mercury, and, after it has attained full running speed, must continue to rotate for at least 18 min. after the suction has been shut off. The sensitivity must be within the limits quoted in the relative specification, when tested in the usual manner on a smoothly turning turntable, of which the speed can be varied. Light tapping of the instrument is permissible during test, to overcome friction at the pivot which would normally be overcome by the vibration of the instrument panel during flight. The damping of the turn unit and pendulum unit must be such that after a given displacement the pointer shall not overshoot the zero, on its return, by more than half a division. The range of the pendulum unit is 20° either side of zero, and the errors must not exceed plus or minus 0.5° at the zero, and plus or minus 2.0° at any other part of the scale. To test for freedom of the pendulum, the

instrument should be placed with the dial at 75° from the vertical both backwards and forwards and swung slowly from side to side.

Installation and Maintenance

The indicator is fitted to the instrument panel, so that the cross-level pointer is central when the aircraft is in normal flying attitude. The Venturi is fitted with its axis horizontal and the bracket end facing forward in the slip-stream, where the air current is unobstructed and free

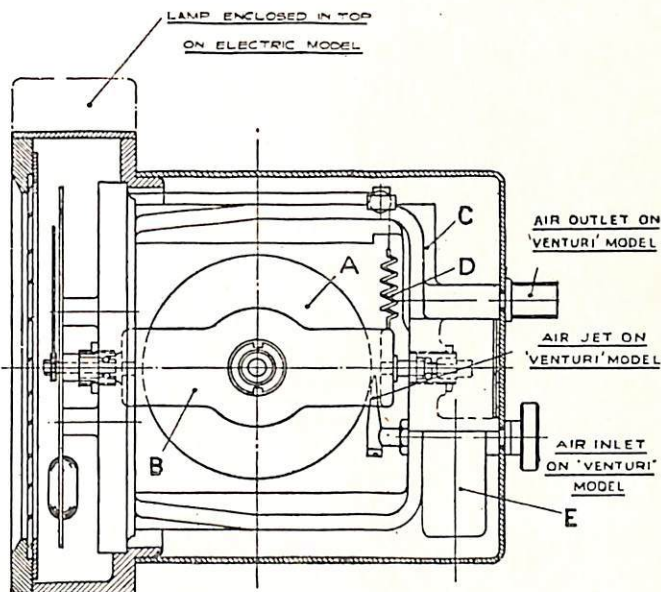


FIG. 44. MECHANISM OF "BROWN" TURN INDICATOR

A. Wheel
B. Inner frame
C. Outer frame

D. Control spring
E. Dashpot

from oil mist; a good position can usually be found on the centre section strut. Nipple connections are provided on the indicator and Venturi for connecting up with the pipe-line by means of low pressure unions. Occasionally, say after every 300 hours' flying, the inside of the Venturi should be cleaned and the neck examined to see that there are no accumulations of dust or dirt. The connexions should be tested for airtightness, and the bezel of the instrument case screwed home so that no leaks occur. Occasionally the pipe lines should be disconnected and a stream of air from a pump passed through them to ensure freedom from obstruction or moisture. The filter over the air jet of the instrument should be removed and the gauze cleaned. It is readily accessible if the three small screws securing the filter cap are removed.

The "S. G. Brown" Venturi (Type A) Turn Indicator

The "S. G. Brown" Venturi (Type A) Turn Indicator consists essentially of a small wheel revolving at 3,500 r.p.m. The axis of the wheel is set horizontally and is mounted in a small frame, which in turn is mounted

in an outer frame fixed to the body of the instrument. The outer frame carries a graduated card on its forward end. The spindle of the front bearing frame is extended through this card and attached to a pointer,

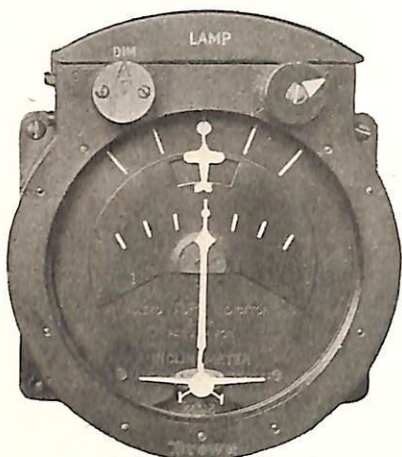


FIG. 45. "BROWN" (Type E)
TURN INDICATOR

the five positions of the switch in the top right-hand corner of the instrument case. An on-and-off switch in the top left-hand corner of the instrument in or out of action as required.

An inclinometer is incorporated in the instrument, and consists of a pendulous damped pointer operating over a scale marked at each 10 degrees of tilt.

On the glass inside the instrument is painted a fixed datum line in the form of a small aeroplane. If the machine banks, left wing low, the pointer will keep still vertical, but the small aeroplane will appear to be left wing down. All that is necessary to bring the aircraft level is to follow the apparent motion of the indicator to the right with the control column. When the aircraft is correctly banked during a turn, the pointer remains in the centre of the scale.

which moves over a graduated scale as the wheel and its frame are tilted from the horizontal. In plan view the pointer is in the shape of a small aeroplane. A pipe is led in from the back of the outer case through the outer frame, and terminates in an air jet which impinges in serrations or cups mounted in the periphery of the wheel. The outer end of the pipe is fitted with a fine gauze-covered screw cap, which prevents the ingress of dust. The inner frame carries two pistons operating in cylinders to provide suitable dashpot damping.

A small spring (of which the tension can be varied by the manipulating of a small knob on the front of the case) controls the horizontal position of the inner frame. The sensitivity is adjustable to any of

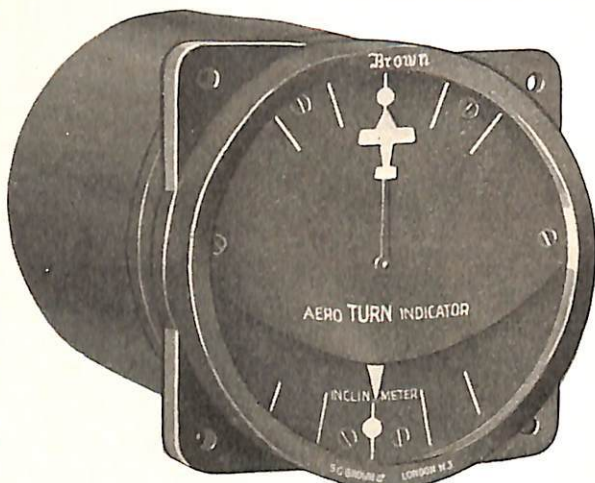


FIG. 46. "BROWN" VENTURI MODEL TURN
INDICATOR (NEW TYPE)

The "S. G. Brown" (Type E) Turn Indicator

The "S. G. Brown" (Type E) Turn Indicator is an instrument of similar construction to the Venturi type, but is driven electrically from a 12-volt battery, the working current being $\frac{1}{2}$ amp. It is internally illuminated and, as the pointer moves to left or right during a turn, red or green windows are uncovered. A dimming switch controls the amount of illumination.

The New "Brown" Venturi Model Turn Indicator

A new "Brown" Venturi Model Turn Indicator has been produced quite recently by Messrs. S. G. Brown. In this instrument, great attention has been paid to the damping of the gyroscopic element, and a very exact zero is obtained on the turn indicator. The sensitivity adjustment and the on-and-off control have been eliminated, thus simplifying the instrument, which is more robust than the earlier types and occupies less room on the instrument panel. A very important point is that the inclinometer pointer gives reverse readings to the older types.

The "Hughes" Turn and Bank Indicator

The "Hughes" Turn Indicator embodies a gyroscope wheel mounted in a gimbal ring pivoted fore-and-aft of the instrument case, the pivots being rigidly attached to the case. The gyroscope wheel is air-driven by means of a Venturi tube which creates partial vacuum inside the case. The air is sucked in through a nozzle and then impinges on peripheral slots cut in the wheel.

Movement of the case in azimuth gives rise to a precessional movement of the wheel, which in turn actuates the indicating pointer. A suitable return spring is incorporated, the tension of which determines the sensitivity of the instrument. Oscillation of the moving parts is controlled by air-damped pistons.

The Bank Indicator consists of a steel ball free to move in a radial glass tube, and suitably damped by means of a non-freezing liquid.

The Sperry Horizon and Directional Gyro have been designed to give direct and immediate indications of the movement of an aircraft in three directions—

The Sperry Horizon provides a visual picture of the attitude of the aircraft (represented by a miniature aeroplane on the dial) relative to an "artificial horizon" bar moving across the dial of the instrument.

The graduations show the *actual degree of bank* during a turn. The pitch, when climbing or gliding, is indicated by the position of the miniature aeroplane above or below the horizon bar.

The gyro is maintained in rotation by air suction from a Venturi or

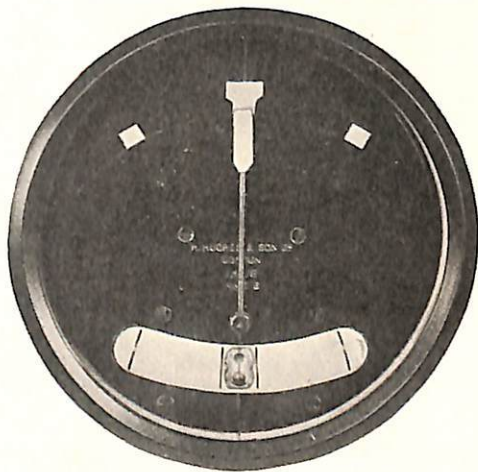


FIG. 47. TURN AND BANK INDICATOR
(Henry Hughes and Son)

air pump, and is mounted so as to spin in a horizontal plane about a vertical axis.

Four horizontal jets connect to equally spaced openings at the bottom of the gyro case. Over these openings hang vanes, so disposed that when the gyro axis is vertical, half of each opening is covered by its vane. If the gyro axis inclines away from the vertical, one vane covers more than half (and the vane on the opposite side covers less than half) of its respective

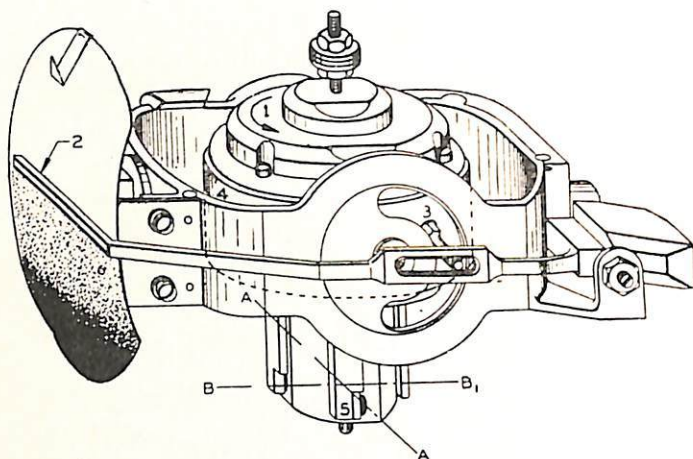


FIG. 48. DIAGRAM OF "SPERRY" HORIZON
(Sperry Gyroscope Co.)

- | | |
|------------------|-----------------|
| 1. Gyro axle | 4. Gyro case |
| 2. Horizon bar | 5. Hanging vane |
| 3. Actuating pin | |

opening. Consequently the air stream through the jet is increased on the side on which the opening is greater and the added reaction on the casing causes the gyro to "precess," i.e. to tilt in a direction at right angles to the applied force.

The restoring action of the precessional forces is arranged so that the axis of the gyro is never allowed to incline more than two degrees from the true vertical. The horizon bar is actuated by a pin protruding from the gyro case through a slot in the gimbal ring. For all practical purposes, the horizon bar acts as an artificial horizon, when the natural horizon is not visible.

The Sperry Directional Gyro is also actuated by air suction from a Venturi or air pump.

A circular Compass Card graduated in degrees is attached to the vertical ring on which the rotor and its gimbal ring are mounted. The vertical ring and card turn freely in azimuth in the vertical bearings and a portion of the card is visible through a small window in the front of the instrument case.

When the gyro is rotating, its axis and supporting ring as well as the Compass Card remain fixed in azimuth and thus any rotation of the aircraft will be indicated by a movement of the card relative to the datum mark across the window. The gyro is subject to slight drift (approximately 2° per 15 to 20 minutes) and therefore needs resetting, from time to time,

by pressing and turning the knob below the dial until the reading agrees with that of the Magnetic Compass.

It should be noted that these instruments show the actual number of degrees turned through and not the *rates* of turn as in some types of turn indicator.

Unlike bubble types of spirit levels and pendulum devices, they are

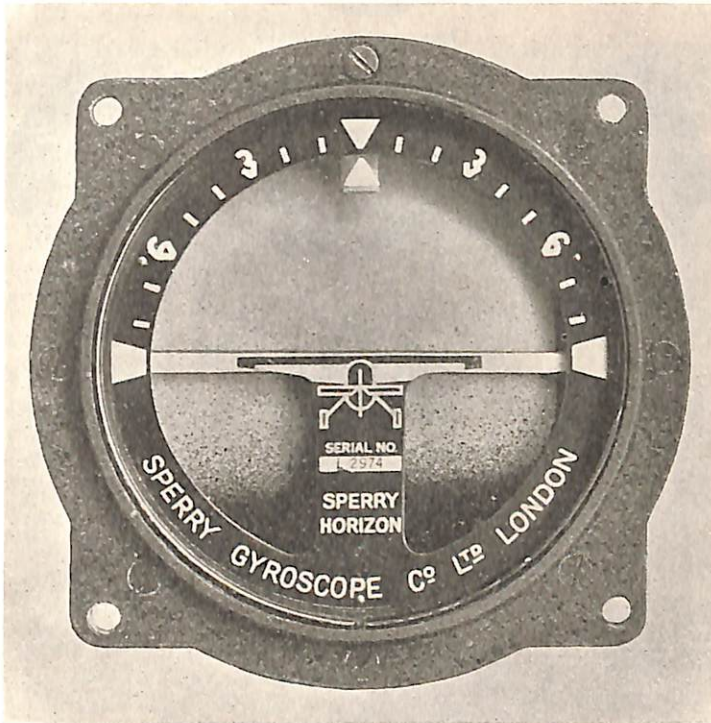


FIG. 49. "SPERRY" HORIZON
(Sperry Gyroscope Co.)

not subject to acceleration forces due to turning or changes in speed. The instruments are designed to give the pilot direct information as to how far he may have steered from a given course and how far he must turn to proceed on a new course.

10. COMPASSES

The Aircraft Compass has to be specially designed to meet the particular conditions in which it is used in the air. When the speed of the aircraft is changing, or when the aircraft is executing a turning movement, the readings of an ordinary compass are unreliable.

The reasons for the inaccuracies introduced may be appreciated by considering the forces on a simple magnetized needle freely suspended at its centre of gravity. The magnetic axis tends to set itself in the magnetic meridian under the action of the earth's magnetism, and the resultant

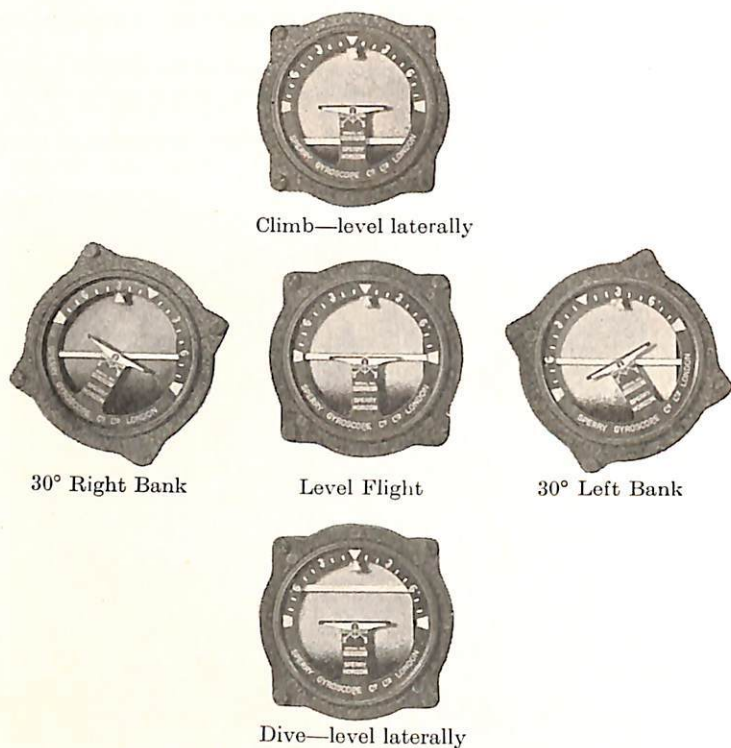


FIG. 50. INDICATIONS OF "SPERRY" HORIZON
(Sperry Gyroscope Co.)

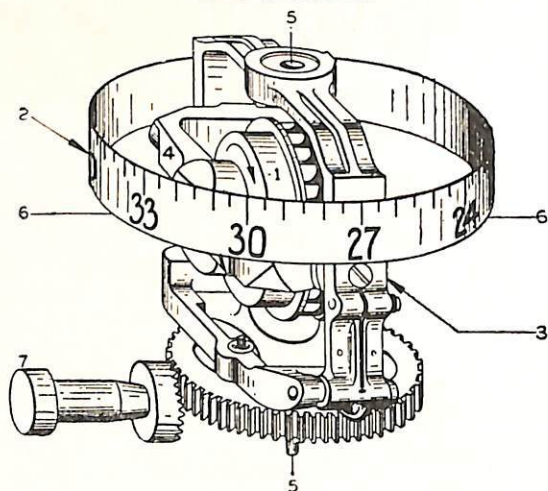


FIG. 51. DIAGRAM OF THE "SPERRY" DIRECTIONAL GYRO

1. Gyro wheel	3. Vertical supporting ring	5. Bearings	7. Setting knob
2. Compass card	4. Gimbal ring	6. Gyro axle	

force may be resolved into horizontal and vertical components, which may be considered separately. The vertical component causes the needle to dip slightly. The horizontal component causes the needle to point to the magnetic North. Its value is very small—about $\cdot 185$ dyne ($= 1/30,000$ oz. wt.).

In an aircraft compass, the magnet system consists of a number of magnetized needles arranged parallel to one another in such a way that

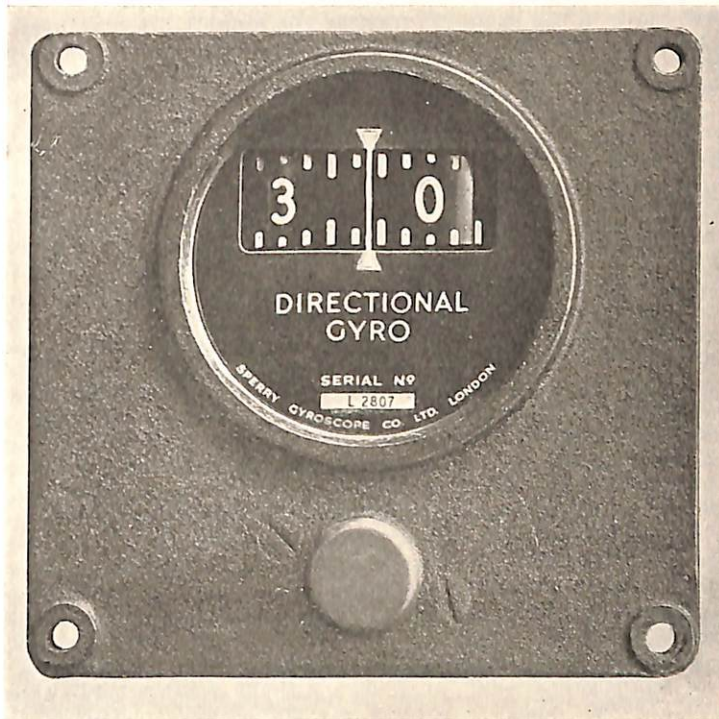


FIG. 52. "SPERRY" DIRECTIONAL CYRO
(Sperry Gyroscope Co.)

the inertia is small in comparison with the magnetic moment, and the system is balanced both statically and dynamically. The directional error should not be greater than 1° . The centre of gravity of the pivoted system is kept well below the point of support, so as to make the angle of dip due to the vertical component of the earth's magnetic force as small as possible. Except on the equator, the magnet system will dip¹—with the north-seeking end (marked "N") downwards in the northern hemisphere, and with the south-seeking end (marked "S") downwards in the southern hemisphere. In the former case, the centre of gravity will be displaced to the south if the aircraft is flying eastwards. If the aircraft suddenly in-

¹ The magnet system should be constructed so that its dip will not exceed 3° anywhere between the latitudes 60° N. and 60° S. In England, it should be north end down by an angle not exceeding 2° .

creases speed, acceleration forces acting at the centre of gravity will produce a deviation in a clockwise direction. On the other hand, a decrease in speed will produce anti-clockwise deviations. The error introduced is called the **Speed Error**, and is most serious when the speed is suddenly changed on east and west courses.

When the aircraft turns, centrifugal forces acting at the centre of gravity produce what is called the **Northerly Turning Error**. Suppose the aircraft makes a banked turn when heading magnetic north. The N. end of the magnet system moves downwards, and the compass card will move in the same direction as the aircraft. It may even turn faster than the aircraft and produce the effect of a turn in the opposite direction. In the early days of flying the northern turning error was not understood, and a pilot's attempt to counteract the apparent turn in the other direction often resulted in a spin. Double pivoted compasses (in which the compass card is horizontal when the pivots are in a vertical line) have been introduced; they are unaffected by turning error when making a flat (unbanked) turn.

In order to minimize oscillations, the magnet system must be designed so as to be as dead-beat as possible, that is, if the magnet system be displaced from the meridian, it must return to the equilibrium position in the minimum time. This condition is secured by devices such as damping filaments, the movements of which through the liquid do not cause movement of the liquid as a whole, but merely set up eddies which are quickly dissipated. Compasses in which the magnet system after deflection returns to the equilibrium position directly without oscillating are said to be **Aperiodic**. Pivot friction is reduced to a minimum by the use of agate or iridium pivots in sapphire bearing-cups, so that the relatively weak forces due to the earth's magnetism may give a clear indication on the compass card. A tilting freedom of 15° is usually allowed in all aircraft compasses—that is to say, the magnet system must be free to move if the bowl is tilted to any angle not exceeding 15° .

The use of liquid in the compass bowl assists in damping out oscillations and vibrations and also serves partially to support the magnet system, and enable it to respond more freely to movements of the aircraft. Usually a solution of alcohol is used on account of its low freezing-point¹ and small coefficient of expansion. The compass should withstand a wide range of temperature (-25° to $+50^\circ$) without derangement. Over the range named, the change in volume of a 90 per cent solution of alcohol in water is approximately 12 per cent, and an expansion chamber is usually incorporated to allow for this. A further reason for the use of alcohol in compasses is its low viscosity. If the compass bowl is turned in azimuth, the liquid tends to be dragged round with the bowl and eddies are set up at the circumference. These penetrate towards the centre and set up rotation in the magnet system. This effect is known as "liquid swirl," and is minimized by the use of liquid of small viscosity.

Alcohol acts on most paints, many metals, and on sulphur (often used in the rubber jointing washers), and causes the liquid to become discoloured in course of time. Special paints are employed, or the interior of the compass bowl is often coated with vitreous enamel in order to avoid this trouble.

Various shock-absorbing devices have been adopted in order to minimize the effect of vibration.

¹ Whatever the composition of the liquid, the freezing point should be below -35°C .

This survey of some of the principal problems involved in the construction of aircraft compasses will enable the student to appreciate more fully the following notes on approved types, and the hints for installation, maintenance, and adjustment.

Approved Types of Compasses

Several types of Compass have been approved for use on civil aircraft. Specification No. 9 (see p. 132) lays down the minimum requirements.

TYPE 6/18.

The type 6/18 Compass is aperiodic (see p. 68). The magnet system carries eight radial damping wires, spaced at 45° , four of which are marked N., E., S., and W. respectively. A rotatable grid ring is fitted above the bowl, and can be locked in any desired position by two locking levers. The ring is graduated every 2° . Four parallel wires (the grid wires) are fitted across the grid ring. The lubber line is marked inside the bowl, and is visible at the edge of the glass. In determining a course, the grid ring is turned until the grid wires are parallel to the N.-S. wires of the moving magnetic system, and the N. wire registers with the N. mark on the ring. The ring is then clamped, and the course is indicated by the mark of the scale which registers with the lubber line.

TYPE P2.

The P2 Compass is a modified form of type 6/18. The bowl is enclosed in a cylindrical container, and its interior is coated with a vitreous enamel which is not so likely to be affected by alcohol as paint. The grid ring can be removed by unclamping and setting the N. mark against the lubber line. On raising the N. side of the ring it can be lifted off to allow the glass front of the compass bowl to be cleaned without risk of damage to the grid wires.

TYPE P3.

Type P3 Compass was designed for use in aircraft where (for reasons of restrictions of space) it is necessary to fit the compass at or about the level of the pilot's eye. Through the vertical verge glass, the compass card with graduations marked on its rim can be seen against the black painted background of the interior of the spherical compass bowl. This arrangement gives the maximum range of vision in the vertical plane. The magnet system, damped by four glass damping filaments, carries the cylindrical compass card, marked every 5° . On the verge glass a luminous lubber line is painted. The cardinal points (N., S., E., and W.) and the quadrantal marks (N.E., S.E., S.W., and N.W.) are also luminized, and a small electric lamp is fitted at the top of the verge ring. The corrector box, fitted below the bowl, is detachable, and contains a number of small bar magnets used in correcting for deviation as explained later. The anti-vibrational devices are of the floating ring and sorbo-sponge bracket type.

TYPE P4.

Type P4 Compass is intended for fitting below eye-level for observation from above. Eight radial damping filaments equally spaced are carried by the magnet system, and are arranged so that the wires marked N. and S. are parallel to the compass needles. The grid ring, fitted above

the bowl, can be rotated and locked in any desired position by a clamping device. Its inner circumference is graduated every 2° , and carries four wires (the grid wires) which can be set, parallel in pairs, to the damping filaments marked N.S. and E.W. The course is then read off against the lubber line which is marked on the inside of the bowl. The N.S. and E.W. cross-filaments and the lubber line are made in the form of sealed glass capillary tubes to obviate any action of the alcohol on the luminous compound. The grid ring may be removed for the purpose of cleaning and lubricating the under rim, by unscrewing the three countersunk brass screws by which it is attached to the top of the bowl.

TYPE O2.

The type O2 Compass was designed for use by the observer or navigator, and can be mounted on suitable mountings in various parts of the aircraft, so that bearings can be taken either to left or right of the flying axis. The magnet system is heavily damped, and carries a small mica card (graduated to 2°) with letters and numbers reversed so that they appear in normal position when read through a magnifying prism mounted on the verge ring, which can be rotated and locked in position as desired. A sighting device consisting of a reflector and two coloured glasses can be adjusted by a knurled screw. The fixed lubber line enables the course to be read through the prism; thus the compass can be used to steer a course, or to keep a given course.

Standard fittings are provided for housing the compass either on the left or right side of the aircraft, and these are suitably marked to ensure that the compass is inserted in the correct position.

TYPE O2T.

The O2T Compass is arranged so as to enable a setting of the variation to be made by means of a pointer against a scale. The compass unit is capable of rotation in order to bring the pointer into register with the variation figure and is then locked in position by means of a wing nut. All bearings and courses read off against the lubber line will then be "true." A magnifying prism is used but there is no centesimal scale.

TYPE O3.

Type O3 Compass is also designed primarily for the observer and has a centesimal scale. This obviates the necessity for a large compass card. The four damping filaments are marked 0, 1, 2, and 3, and register against a scale of 100° fixed to the side of the bowl. The markings on the filaments represent hundreds of degrees, and a reading is taken from the one which registers on the scale. Thus, if the filament marked 2 registers on the 24° mark on the scale, the reading is 224° . Another set of four filaments consists of sealed glass capillary tubes containing luminous compound and point N., E., S., and W. The N. filament carries an arrowhead. A short luminous tube acts as a lubber line. A rotatable azimuth¹ circle or verge ring is fitted above the bowl, and carries a glass prism through which the reversed markings on a small mica card (mounted on the magnet system) can be read. The azimuth circle can be locked in position if desired, and is made detachable.

¹ The azimuth is the angle between the bearing of an object and the meridian line.

TYPE O4.

Type O4 Compass is intended to be held at eye-level by the handle provided, while bearings are being taken. The object is "sighted," and

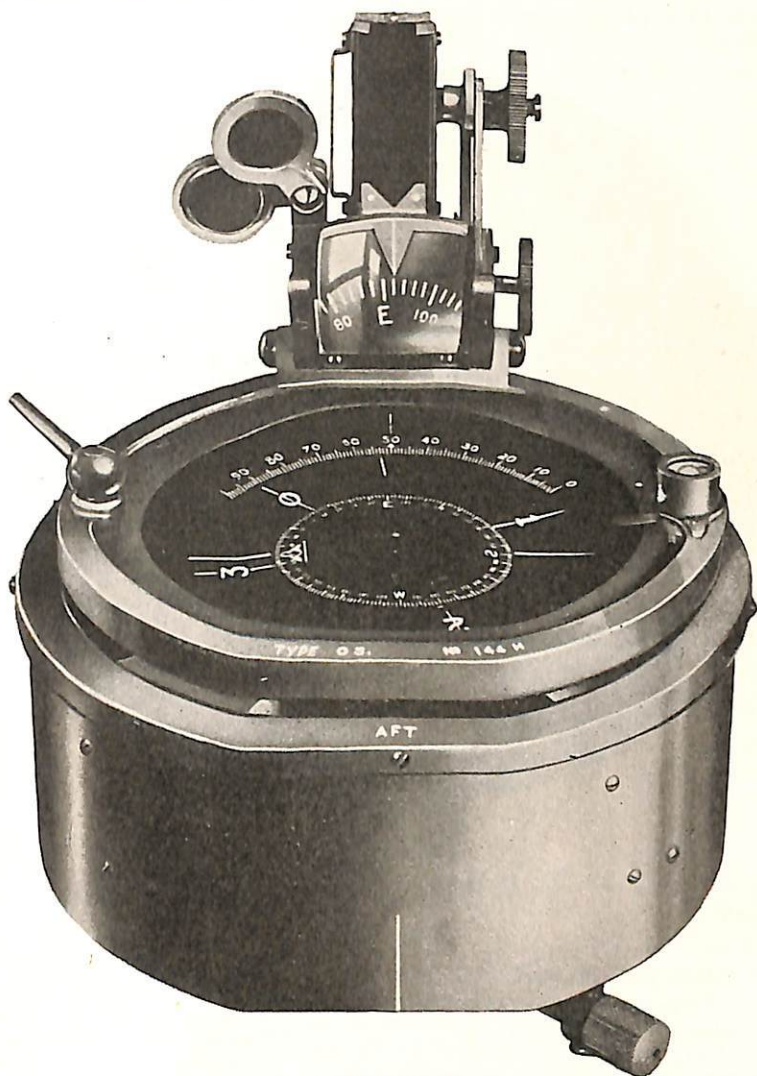


FIG. 53. COMPASS (TYPE O3)
(Henry Hughes and Son)

the bearing read off from the portion of the compass card which is seen through the magnifying prism. The handle is hollow and contains a small battery and lamp for illuminating the compass through the glass bottom of the bowl. A switch on the handle controls the lamp. A special

bracket is provided for convenient stowage or mounting in various positions in the aircraft.

TYPE P6.

The P6 type Compass is one of the same type as P4, but considerably smaller.

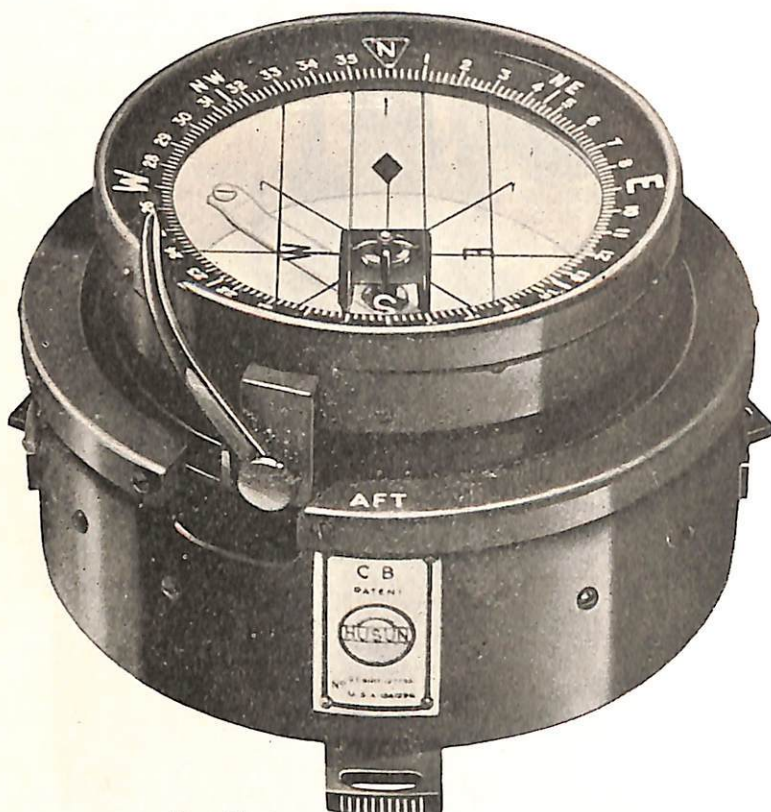


FIG. 54. COMPASS: "HUGHES" MARK IIIA
(Henry Hughes and Son)

TYPE "HUGHES" MARK IIIA.

The "Hughes" Mark IIIA Compass is fitted with a rotatable grid ring carrying four parallel grid wires. The scale is divided into 360° by 2° intervals. In setting a course the grid ring is rotated until the desired course shows against the lubber line. The grid ring is then clamped and the aircraft is steered in such a way as to keep the N.-S. pointer parallel to the grid wires, with the red arrow pointing to N. on the grid. Special suspension arrangements have been adopted in order to reduce the effect of vibration or shocks of landing to a minimum. Provision is made for the adjustment of the grid wires by turning a small slotted nut at the ends of the wires. A micro-adjuster is fitted to the underside of the compass bracket immediately beneath the centre of the compass, and is

operated by keys, one for fore-and-aft adjustment, the other for athwartships adjustment when correcting for deviation. This takes the place of the corrector magnets used in many other types.

TYPE K.B.B.4.

The K.B.B.4 type Compass, manufactured by Kelvin, Bottomley & Baird, is similar to P4 type, carrying four direction indicators and a



FIG. 55. COMPASS: TYPE K.B.B.4
(Kelvin, Bottomley and Baird)

graduated verge ring provided with parallel grid wires. By suitable choice of the weight acting on the pivot, the magnetic moment, and the moment of inertia of the damping elements, the "period" (the time which the magnet system takes to return to the equilibrium position after displacement to 90°) is reduced to $6\frac{1}{2}$ sec. and the overswing to 4° .

The compass is provided with inverted pivots, that is, the pivot point is carried by the moving magnet system, the jewel being carried in the central pillar. This is an advantage where the compass is subjected to much vibration.

TYPE SESTREL II.

The "Sestrel" type Compass, Mark II (made by H. Browne & Son), is also similar to P4. A special feature is the lightness of the magnet

system, which weighs only $1\frac{1}{2}$ grm. A micro-adjuster for correction of deviation is fitted, and there is also a locking device to prevent the possibility of movement of the magnets under vibration. The adjusting keys will only turn easily when two locking screws are slackened. On retightening these, the magnets are prevented from shifting.

TYPE "C," DENT & CO. & JOHNSON.

Dent & Co. & Johnson type "C" Compass is constructed on similar lines. The weight of the moving magnet system is $1\frac{1}{2}$ grm., and with 30° deflection the overswing is only $1\frac{1}{4}^\circ$. The period is 6 sec. The interior of the bowl is blacked so that the luminized elements of the magnet system and the lubber line show up clearly in all circumstances. The compass is provided with the usual rotatable verge ring, with clamping device, and two parallel grid wires for setting parallel to the N. pointer of the magnet system.

The duties of the ground engineer in regard to compasses may be summarized as follows—

1. Inspection before installation.
2. Inspection after installation.
3. Supervision of swinging operations to determine the deviations.

Inspection before Installation

The compass must be examined visually before installation to ensure that it is in serviceable condition. This is not a difficult matter. Special attention should be given to the following points—

1. *Discoloration.* The compass must be reasonably free from discoloration of the card, the bowl, the liquid, or the cover glass. The discoloration is a brownish deposit or sediment due to the slow action of the liquid on the paint. A compass may be considered serviceable if the course can be read without difficulty under conditions of lighting which would be experienced normally in flight. It must not be forgotten that sediment collected in the bottom of the bowl may be thrown into suspension under vibration, and this effect should be taken into account. The bowl should not be dented as the enamel is likely to chip away at the dent.

2. *Pivot Friction.* Pivot friction is perhaps the most common defect in compasses, and a serviceable compass is reasonably free from this defect. The following simple test should be made. The compass should be supported on a level surface and the reading noted. If the compass is installed in the aircraft, the latter should be set approximately in flying attitude. A corrector magnet is then brought up close to the bowl, at right angles to the magnet system, thus causing a deflection of the latter to about 10° . The corrector magnet is then removed to a distance and the magnet system allowed to come to rest. If free from pivot friction, it will settle down to its original position. The compass may be considered serviceable if there is no more friction than can be eliminated by tapping the bowl with the knuckle—equivalent to the vibration of the aircraft. The friction is of the order of 1° at normal temperature. Discoloration is often associated with pivot friction.

3. *Anti-vibration Devices and Moving Parts.* The anti-vibration devices and all working parts should be examined for condition and freedom of

action. Verge rings and sighting mechanism should move freely. If the motion of the ring is not perfectly free, the ring should be removed and cleaned and lightly lubricated with a smear of vaseline mixed with powdered graphite. A broken spring must be replaced.

4. *Air Bubbles.* The bowl must be completely filled with the liquid recommended and supplied by the makers. Even a small bubble may result in a disturbance of the liquid ("liquid swirl") which causes the magnet system to oscillate, and makes it practically impossible to steer a correct course. This is especially serious in the case of aperiodic type compasses. If a bubble constantly forms there is probably a leak in the bowl or at a joint, or the liquid may not have been properly de-aerated before sealing.

De-aeration of Compasses

It is important that the liquid used in compasses shall be free from dissolved air, which is liable to form a large bubble when the external pressure is reduced, as in the case of a climb to a high altitude. The only satisfactory way of ensuring this is to de-aerate both the liquid (in the filled compass) and the filling-plug washers (which are made of compressed fibre and contain an appreciable quantity of air); then, to remove the bubble by filling up with de-aerated liquid and, finally, to seal up the compass.

The following standard method has been found to give entirely satisfactory results—

1. The expansion chamber beneath the bowl has a small tapped hole on its outer edge directly underneath the filling plug on the bowl. A small screw and washer to fit the hole should be at hand.

2. The compass should be filled in the ordinary way, and then placed in a suitable chamber, from which the air can be gradually exhausted by means of a pump. The apparatus is similar to that used for testing altimeters—described on p. 48. The compass should be placed so that the glass is vertical and the filling plug socket uppermost. The plug should be removed.

3. The filling plug washer and a small quantity of compass liquid should be placed in a beaker, and the beaker placed beside the compass in the chamber.

4. The pressure in the chamber is then reduced to about 2 in. of mercury, and the apparatus is left for at least one hour in this condition.

5. On removing the compass, the bubble caused by the de-aerating process is removed by carefully pouring in (without splashing) some de-aerated liquid from the beaker. This drives the air in the expansion chamber through the small tapped hole, and so completely gets rid of the bubble in it. The compass is then finally sealed, by screwing first the small screw with its washer, and then the filling plug with its washer, into their respective holes. This operation should be performed as quickly as possible (say in three or four minutes) as air is gradually re-dissolved so long as the liquid is exposed to the atmosphere.

6. The expansion chamber should be distended as required to allow for the temperature at which the compass has been filled. This precaution is not necessary if the expansion chamber has been previously given a permanent set to allow for filling at 15° C.

Compasses thus de-aerated have been subjected to a range of temperature from +15° C. to -50° C., and to a range of pressure from 8 to 30 in. of mercury, without air bubbles forming.

Inspection after Installation

The inspection after installation should be carried out systematically, to ensure that—

(a) The compass is an approved type. Present types approved are: 6/18, P2, P3, P4, P6, O2, O3, O4, Hughes IIIa, K.B.B.4, Sestrel II, and Dent & Co. & Johnson "C," which have already been briefly described.

See also Civil Instrument Specification No. 9 (p. 132).

(b) It is positioned in accordance with the installation drawings.

(c) No damage has occurred during installation.

(d) No ferrous material has been employed for the support or platform, and that only brass fixing screws and bolts and nuts have been used.

(e) No part of the aircraft is in contact with the compass bowl.

(f) The attachment of the compass to the aircraft is rigid, and the magnet system is in the normal untilted position when the aircraft is in normal flying position.

(g) The vertical plane through the centre of the compass and the lubber mark coincides with (or is parallel to) the vertical plane through the fore-and-aft axis of the aircraft. The lubber mark should be to the front. In most compasses the fore-and-aft line is marked by white lines on the container, and usually the securing lugs have curved slots to permit slight rotation of the compass, if necessary in making any adjustment.

(h) If the corrector box is a separate fitting, it is placed centrally under the compass bowl, with the holes for the magnets exactly fore-and-aft and athwartships respectively. The fore-and-aft line usually marked by a line painted on the box.

(i) No added fittings of ferrous metal are near enough to the compass to affect its readings.

Deviations

A compass installed in an aircraft is subjected to disturbing influences due to the presence in its vicinity of iron and steel parts as well as electric circuits. It does not, therefore, give the same indication of a bearing as it would if removed from all such influences, and were influenced solely by the magnetic field due to the earth.

The correction which must be applied to the compass reading to obtain the true bearing is called the **deviation**. It is defined by the number of degrees which must be added (algebraically) to the observed reading of the compass in order to obtain the true magnetic bearing.

Thus, if the compass in an aircraft is headed to magnetic N. and reads 5° , the deviation is 5° West, or -5° , since -5° must be added to the observed reading 5° to get the true bearing 0° . Again, if the aircraft is heading S. and the reading of the compass is 166° , the deviation is 14° East or $+14^\circ$, since $+14^\circ$ must be added to 166° to get 180° , the true bearing. (The compass is graduated 0 to 360° from the north point through E., S., and W., back to the north point.)

The deviation generally varies with the direction in which the aircraft is heading, and can be determined by aligning the aircraft on known magnetic courses in turn, and noting the readings of the compass on each course.

It is sufficient for the pilot to know the corrections for the compass at the **cardinal points** (N., E., S., and W.) and the **quadrantal points** (N.E., S.E., S.W., and N.W.), and these corrections can be determined by heading the aircraft successively to these points in turn. The results are conveniently arranged in the form of a table or curve fixed to the instrument panel in a position close to the compass.

Suppose the aircraft has been headed successively in the directions given in column 1 of the following table, and the corresponding readings have been noted as in column 2. The deviations are calculated as described above and tabulated in column 3.

	1	2 Compass Reading	3 Deviation
N.	0°	348°	+ 12° (E)
N.E.	45°	40°	+ 5° (E)
E.	90°	91°	- 1° (W)
S.E.	135°	142°	- 7° (W)
S.	180°	183°	- 3° (W)
S.W.	225°	227°	- 2° (W)
W.	270°	261°	+ 9° (E)
N.W.	315°	302°	+ 13° (E)

It should be clear that when the correction to be applied has a plus sign, the deviation is to the East of the magnetic meridian. A westerly deviation is always given a minus sign. It will be found more convenient to use the plus and minus signs rather than the terms East and West to describe the direction of the deviation.

These correction figures can be reduced considerably by introducing small bar magnets in the corrector box of compasses to which such a box is fitted. These corrector magnets, of length about 2 in., are usually made in four thicknesses, $\frac{3}{8}$ in., $\frac{1}{8}$ in., $\frac{1}{4}$ in., and $\frac{5}{16}$ in.

The Deviation Coefficients

All the possible magnetic effects in aircraft, due to various iron and steel parts and equipment, may be grouped into five distinct types. The appropriate corrections are called the approximate "coefficients," and are distinguished by the capital letters *A*, *B*, *C*, *D*, and *E*. The method of calculating these coefficients and their application will now be briefly described. For convenience they are dealt with in order, but in practice *B* and *C* should be calculated and correction made before *A*.

The deviation coefficient *A* corrects for—

(a) Incorrect setting of the lubber mark.
(b) Incorrect mounting of the card on the magnet system. This is called the *Card Error*.

(c) An unusual distribution of soft iron in the aircraft.

The coefficient *A* is the same on all bearings. It is calculated (from the figures given above) as follows—

$$\text{Mean deviation} = \frac{+12 + 5 - 1 - 7 - 3 - 2 + 9 + 13}{8} = \frac{+26}{8} = +3\frac{1}{4}^{\circ}$$

To correct for this, loosen the clamping bolts and turn the compass clockwise through $3\frac{1}{4}^{\circ}$, reading the $3\frac{1}{4}^{\circ}$ from the compass, then reclamp. If the mean deviation had been negative, the compass would have to be turned anti-clockwise.

Correction *A* cannot be made for P3 or P5 types of compasses.

The deviation coefficient *B* corrects for magnetic effects which may be considered as similar to those which would be produced by an imaginary magnet placed in the fore-and aft line of the aircraft. The greatest effects will be produced on the E. and W. bearings. *B* is half the difference

(algebraical) of the deviations on the East and West points, and is calculated from the figures given above thus—

$$\begin{aligned}\frac{\text{Deviation on E.} - \text{deviation on W.}}{2} &= \frac{(-1) - (+9)}{2} = \frac{-1-9}{2} \\ &= \frac{-10}{2} = -5^\circ\end{aligned}$$

It is important to substitute the values for the deviations with their proper signs.

To correct for this, place one or more magnets in the fore-and-aft holes of the corrector box when the aircraft is heading E. or W., until the compass reading *changes* by as nearly as possible 5° . It should be clear that to correct for $B = -5^\circ$, the blue (south-seeking) ends must be placed forward. To correct for $B = +5^\circ$, the red (north-seeking) ends must be placed forward.

The deviation coefficient C corrects for magnetic effects which may be considered as similar to those which would be produced by an imaginary magnet placed athwartships in the aircraft. The greatest effects will be produced on the N. and S. bearings. C is half the difference of the deviations on the N. and S. points, and is calculated from the figures given above thus—

$$\frac{\text{Deviation on N.} - \text{deviation on S.}}{2} = \frac{(+12) - (-3)}{2} = \frac{+15}{2} = +7\frac{1}{2}^\circ$$

each value being substituted with its proper sign as before.

The deviation coefficients D and E correct for the presence of soft iron magnetism in the aircraft. The greatest effects of D appear on the quadrantal points, and those of E on the cardinal points. These coefficients are not of particular importance and need not be considered here.

Just as the earth's magnetic field may be considered equivalent to that of an imaginary magnet with poles situated near to the earth's magnetic poles, so the magnetic field due to the presence of magnetic material in an aircraft may be considered as equivalent to that which would be produced by an imaginary magnet with its distinct poles in the aircraft. In other words the aircraft is considered as acting as a permanent magnet having the line joining its poles lying in some definite direction. The magnetic effect on the compass is the same as that of two imaginary magnets, one in the fore-and-aft axis and the other athwartships. These two magnets were referred to in the discussion of deviation coefficients B and C above.

Soft iron (that is iron which becomes magnetized in a magnetic field, but which does not retain its magnetism when removed from the field) may occur in various parts of the aircraft, and affect the compass on account of the magnetism induced in it by the earth's magnetic field. Its effects can be compensated by adjusting the position of soft iron spheres near the compass, as is customary on ships.

Adjustment of the Compass

It is advisable to adopt a definite routine in adjusting the compass, in order to economize both time and labour. The following preliminary precautions should be observed—

1. The compass should be examined as previously described. Any defects must be remedied or the compass must be replaced by one that is not defective.

2. All magnetic steel, tools, etc., should be removed from the aircraft, unless carried during flight in fixed positions.
3. All gear, such as wireless apparatus, which could possibly affect the compass during flight, should be in position.
4. All keys, magnets, etc., should be removed from the pockets.
5. The corrector box should be emptied of magnets and the latter removed to a distance.
6. The aircraft must be in normal flying position. The tyres must be equally inflated.
7. If more than one compass is fitted, readings and/or corrections of all compasses should be made on each bearing before moving the aircraft to the next bearing.

Adjustment by Use of a Landing Compass

The aircraft is set up in the open, at least 50 yd. away from masses of iron, such as hangars, railway lines, and 100 yd. from an electric or wireless generating station, or underground cable carrying a heavy current. Plumb lines are suspended from the centre of the propeller boss and the centre of the rudder post. The axis of flight of the machine will be in the vertical plane through both plumb lines. About 50 ft. to the rear and in line with the plumb lines the landing compass is placed in position and levelled. By sighting through the slot and hair-line of the compass on the plumb lines, the magnetic bearing of the aircraft is obtained. The difference between the magnetic bearing thus obtained and the reading of the compass in the aircraft gives the deviation. The aircraft is then swung round, approximately about a fixed pivot point, and the landing compass is moved to a new position, at about the same distance as before, and again aligned with the plumb lines. Local objects may often be chosen conveniently, lying approximately in the directions of the cardinal points, as determined by the landing compass. The aircraft is then placed in line with these objects in turn. Readings are taken in successive positions as before and the results are plotted on squared paper. A curve is then drawn from which the figures for the cardinal and quadrantal points can be obtained for recording on the deviation card.

Adjustment by Use of Swinging Base

At many stations a swinging base is marked out permanently, by eight lines radiating from a centre, in the directions of the cardinal and quadrantal points.

The aircraft is headed N., E., S., and W. in turn, and the deviation in each position recorded. The correction on the N.-S. line is then made as explained above (coefficient *C*). The aircraft is then headed W., the deviation is noted, and coefficient *B* is calculated, and correction made. The aircraft is then swung round so as to head to each of the eight directions in turn; the deviations are noted and correction is made for coefficient *A* if necessary. If the compass bowl is rotated in order to correct for *A*, it will be necessary to correct *all* the readings by the number of degrees through which it was rotated. Final readings should be taken when the engine of the aircraft is running, after which the corrections are entered up on the deviation card.

Swinging an Aircraft Afloat

It is sometimes necessary to determine the deviations when the aircraft is afloat. It will be clear that it is impossible to obtain the same degree of accuracy as on land. Obviously, the best time to choose is on a

calm day and at slack water between tides. One of the following methods may be employed—

1. *The Bearing Compass or Bearing Plate Method.* The aircraft is moored to a buoy and swung round into different positions in turn. From each position a bearing is taken of some prominent object—say three miles distant—by means of a bearing compass in the aircraft. Suppose the bearing is 356° when the aircraft is heading 72° E. The magnetic bearing is found from a chart to be 350° . The deviation is therefore -6° E., and the true magnetic course of the compass at the time of observation was not 72° but 66° . Errors due to swinging and changes in relative position of aircraft and its mooring buoy are neglected. The bearings obtained in each position are plotted on a curve from which the corrections at the cardinal and quadrantal points can be read off and recorded on the deviation card.

A bearing plate may be used instead of the bearing compass. It must be fixed so that the line joining the lubber marks is parallel to the fore-and-aft axis of the aircraft. The zero mark must be adjusted to be in line with the forward lubber mark and the plate clamped in this position. Readings must then be taken from the foresight for different positions of the aircraft as when the landing compass is employed. For each position note the compass reading, which gives the angle between the fore-and-aft line of the aircraft and the magnetic meridian. The true bearings are found by adding (or subtracting) the bearing-plate readings to (or from) the corresponding compass readings. The figures so obtained can be compared with the chart bearings. The differences are the corrections of the compass and are plotted as before. A rough sketch showing the directions of true north, magnetic north, and the distant object should be made to decide whether the readings of the bearing plate must be added or subtracted from the compass readings.

2. *The Landing Compass Method.* A suitable position ashore is selected for the landing compass. It should be free from local magnetic interference. At a signal pre-arranged, simultaneous readings are taken of the bearings of (a) the landing compass from the aircraft, (b) the bearing plate or compass in the aircraft from the landing compass on shore, and (c) each compass to be adjusted. The aircraft is swung round as before into different positions, and similar sets of readings are taken in each case. The results may be conveniently set out in a table as follows—

1 Course by Pilot's Compass	2 Bearing by Bearing Plate	3 Sum of Columns 1 and 2	4 Landing Compass Reciprocal	5 Corresponding Magnetic Course	6 Deviation
318	2	320	323	321	+ 3 (E)
48	282	330	326	44	- 4 (W)

Whatever method is used for the adjustment, care must be taken finally to fasten the covers of the corrector box securely, to note particulars of the magnets used and the number of the engine in the compass log book, and to see that the deviation card is completed correctly and fixed near the compass.

Further details of the theory and the standard methods described above may be obtained from the various official handbooks.

*11. THE STATOSCOPE AND RATE OF CLIMB INDICATOR

The Statoscope

The Statoscope is an instrument for indicating small variations in altitude and is useful in maintaining flight at the same altitude or pressure level. For this purpose the ordinary aneroid form of altimeter is not sensitive enough.

The principle of one type—the Bubble Statoscope—is illustrated below. A "thermos" flask in a suitable container is connected with the curved glass tube seen near the top of the case. The tube contains a small drop of a mobile liquid, of low density, viscosity, and vapour pressure, usually

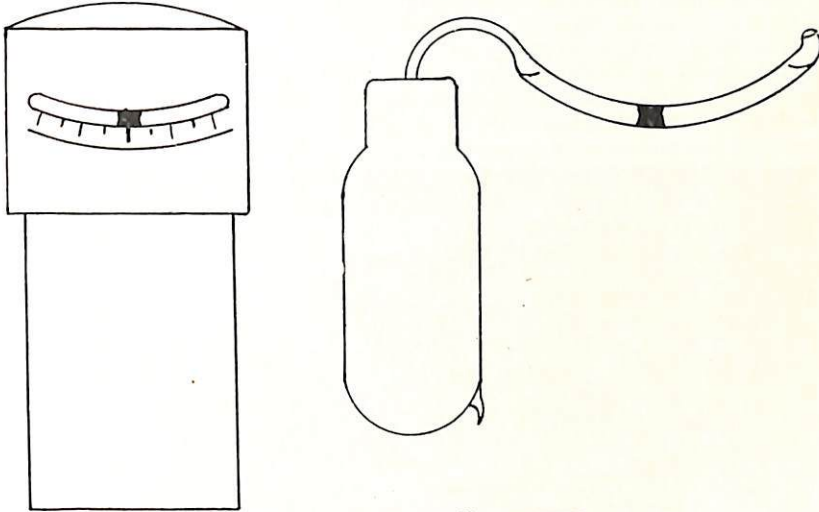


FIG. 56. BUBBLE STATOSCOPE

dyed red so as to be easily visible. The ends of the tube are enlarged or trapped to prevent escape of the liquid either into the external air or back into the thermos flask. As the aircraft rises into regions of reduced air pressure the pressure within the flask is greater than the external pressure. The liquid then moves up to the right-hand trap, where it breaks, allowing air to escape from the flask. When descending, the reverse happens. The liquid moves left, breaks, and air enters the flask. During level flight, the liquid remains stationary. The object of the thermos flask is to render the instrument insensitive to changes of temperature. A scale of sensitivity is sometimes provided and the sensitivity is such that a movement of the liquid from one scale division to the next is effected by change of pressure equivalent to $\cdot 02$ m. of mercury corresponding at ground-level to 20 ft. and at an altitude of 10,000 ft. to 26 ft. difference in height.

In order to maintain level flight, the pilot endeavours to keep the liquid drop in the centre of the tube.

It should be noted that false readings are likely if the instrument is used in an enclosed cockpit.

In testing the statoscope, a small bubble, approximately $\cdot 2$ in., is made with the liquid supplied for the purpose. The instrument is then placed in a vacuum chamber and the pressure reduced at the rate equivalent to

a rise of 1000 ft. per minute to 10,000 ft. During this test the bubble should move up to the right-hand trap, where it breaks allowing air to escape from the flask. When the pressure is increased the reverse happens, namely the bubble makes and breaks on the left. If there is a leak, the bubble will not make and break satisfactorily. The rubber connexions should be examined to verify that they are not perished or damaged, and each instrument should be supplied with a small bottle of red fluid, fountain pen filler and cleaning brush.

Rate of Climb Indicator

Rate of climb can be determined by observing the change in height in a given time. Direct measurements of height are impracticable and the method of pressure difference is usually adopted.

The Rate of Climb Indicator utilizes the principle of the capillary leak. Two separate air chambers are provided with a capillary leak between them. One of the chambers is connected to the outer air by a tube connecting with the static line of the air speed indicator system. The indicator measures the pressure difference between the two chambers. This depends on the rate of climb and the scale is directly graduated in thousands of feet per minute. A screw marked "Zero return" fitted to the front of the instrument enables the pressure in the chambers to be equalized after a climb, by turning the screw anti-clockwise. The screw must then be turned clockwise to close the valve connecting the chambers, so that the instrument is left ready for use.

At the back of the case there is a zero-setting device which is protected by a screw which must be removed before the adjustment can be made. The pressure in the chambers should be equalized before adjusting the zero setting and care should be taken to replace the fibre washer under the screw.

The pressure should always be equalized by manipulating the adjusting screw, before taking an observation. The instrument is very sensitive to changes of temperature, and it is important to neutralize in this way any difference of temperature between the indicator and the static line of the air speed indicator system to which it is connected.

Mark 1b Rate of Climb Indicator utilizes the capacity of its own case with a leak to atmosphere to obtain pressure differences.

Experience has shown that

the best climb is obtained by keeping the air speed (as indicated by the air speed indicator) as constant as possible during the climb. Approximately the best climbing speed is at one-third of the speed range up to the stalling speed. Thus, if the top speed is 150 m.p.h. and the stalling speed 45 m.p.h., the best climbing speed is about 80 m.p.h.

It should be noted that the rate of climb is the vertical component of

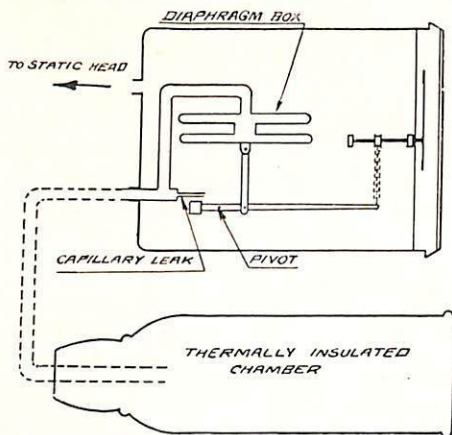


FIG. 57. DIAGRAM OF "HUSUN" RATE OF CLIMB INDICATOR
(Smith's Aircraft Instruments)

the velocity of the aircraft *relative to the air*. This is not necessarily the rate of rising from the ground, which may be affected by vertical currents.

*12. RECORDING INSTRUMENTS

It is often desirable to have a chart record of the changes in altitude, air speed, temperature, or other condition during a flight. For this purpose a number of instruments have been designed. One of these, the Tel Engine Speed Indicator and Recorder, has already been described.

In recording instruments, the mechanism is usually arranged to move a marking pen across a drum to which a paper chart can be attached. The drum is rotated by clockwork and the paper chart has a baseline marked in minutes and a vertical scale marked in suitable units.

Altitude Recorder

In the case of the Altitude Recorder, or Altigraph, the vertical scale is in thousands of feet. The drive is transmitted to the drum through a friction clutch, arranged so that no slip occurs when the drum is turning

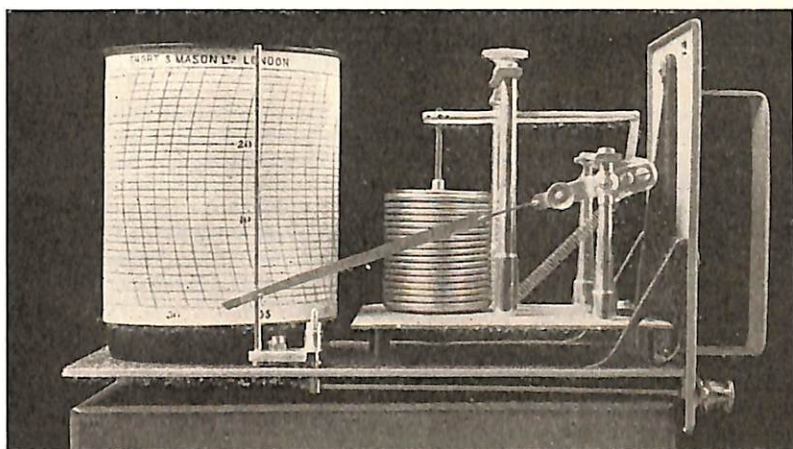


FIG. 58. ALTITUDE RECORDER
(Short and Mason)

while the instrument is operating. The drum, however, may be turned by hand when it is desired to set it to any required position. The clutch may be released and the drum removed for the purpose of replacing the paper chart. Adjusting screws are provided for varying the pressure of the pen on the chart and for setting the zero. A lever is provided for lifting the pen clear of the drum and at the same time stopping the clock. In preparing the Recorder, previous to a flight, the drum is removed and a new chart placed in position with its lower edge in contact with the bottom flange of the drum. The chart is slightly larger than the circumference of the drum, and should be arranged so that the overlap comes under the spring clip which keeps the paper in position. On replacing the drum, care should be taken to align the holes with the two driving pins on the friction plate. The securing nut should be tightened and the drum turned until the spring paper clip is immediately to the left of the pen.

The pen is then charged with the special ink provided and tested on a

piece of paper to ensure that the ink is flowing. See that the pen is correctly positioned on the pen arm, namely, pushed up to the shoulder. Adjust the pen on the zero line of the chart. Wind the clock and verify that it is set for the correct speed of rotation, if two speeds are provided. The positions of the speed change lever are clearly marked, and it must be operated only when the clock is not in motion. Start the clock by operating the starting lever to its fullest extent, when a spring catch will hold it in the ON-position. After use, clean the pen with blotting paper to prevent corrosion and consequent difficulty the next time the instrument is required for use.

Testing Altitude Recorders

Altitude Recorders are tested in the same way as altimeters (see p. 48). A large vacuum chamber will be required, however, of such a size as to accommodate the recorder and a sub-standard altimeter if a mercury barometer is not available. The vacuum chamber is connected through a tap to a reservoir, which can be exhausted by means of a small hand pump. Another tap opens to the atmosphere. The recorder is prepared as described above, but the pen should be set on the chart at a point corresponding to the reading of the barometer as shown by the sub-standard instrument. The clock should be started and the pen be marking satisfactorily before replacing the cover of the vacuum chamber or commencing the test.

A few strokes of the pump will exhaust the reservoir to such an extent as to make it possible to reduce the pressure in the chamber by an amount equivalent to 1,000 ft. in one minute, by manipulating the tap. The tap should then be closed and a few more strokes given to the hand pump during the following minute, which will be sufficient for the pen to record a short horizontal line on the chart. The process is repeated every thousand feet until the maximum is reached. Tests under gradually increasing pressure are then made in the same way, by operating the other tap which opens to the atmosphere.

The corrections applicable to the sub-standard instrument should be added algebraically to the errors indicated by the chart record.

After removal of the instrument from the chamber, the pressure in the reservoir should be released by opening the appropriate tap. The sub-standard should be allowed twenty-four hours' rest before it is used for another test.

Recording Pens (Boat type) give considerable trouble unless they are kept in good condition and adjustment. The following notes (compiled by Messrs. Negretti & Zambra) give some useful hints—

1. Clean the pen in methylated spirit with a brush; if necessary any clogged ink may be removed with a knife, taking care not to open the split.
2. When the pen is moist with the methylated spirit, run a piece of metal foil (not more than .002 in. thick) in the split to clear out any clogged ink.
3. Fill the pen with the recording ink (supplied with the instrument) whilst it is still moist with the methylated spirit.
4. It is most important to prime the split thoroughly with ink. To ensure this, the piece of metal foil may be run along the split when the pen is full of ink.
5. When the pen has been well primed, it may be tested on a piece of paper before fitting to the instrument.
6. The main defects which arise from the boat type of recording ink pens are described in the following paragraphs Nos. 7 to 13.

7. Pen worn and split too open; ink will not flow.
8. Points not touching evenly; pen will not write.
9. Points too sharp and spread open; pen digs in and will not write.
10. Saw cut or split in wrong place; pen will not write.
11. Top edge of pen not level.
12. Split too wide; trace too thick.
13. Point too sharp; trace too thin; pen digs in paper.
14. The pen illustrated will give a good medium trace. The point should be well burnished and slightly rounded to prevent the pen digging in the paper; No. 00 emery paper may be used for slightly rounding the point.

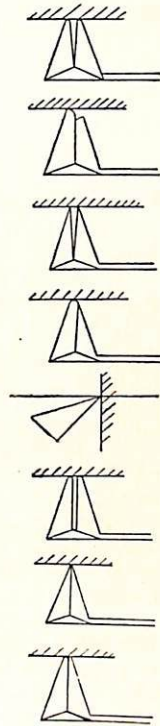


FIG. 59
RECORDING
PENS

APPENDIX I

STANDARDS

A KNOWLEDGE of the use of sub-standards and standards and how to maintain their accuracy is essential for anyone engaged in the testing of instruments.

It should be clear that the accuracy of the standards used must be greater than that required for the instrument under test. Thus, in order to test an air speed indicator to an accuracy of, say, 1 m.p.h., the sub-standard manometer should be capable of measuring accurately at least $\frac{1}{2}$ m.p.h. At 100 m.p.h. this corresponds to a difference of head of water of about 1.25 mm. The reference standard used to check the sub-standard must therefore be capable of measuring a "head" of water to an accuracy of at least .5 mm. (See Section on Air Speed Indicators, p. 40.)

The required accuracy for any particular instrument depends, of course, on the spacing of the markings and on the range. If reference is made to the table of approved types of pressure gauges (p. 12) it will be seen that with a range of 0 - 25 lb. per sq. in., the permissible error is .8 lb. per sq. in., but an error of .2 lb. per sq. in. is permissible with a range of 0 - 200 lb. per sq. in.

Consideration should always be given to the degree of accuracy required for the instrument under test, as well as the degree of accuracy of which the testing apparatus is capable. On test reports, it is usual to state the accuracy of measurement, thus, in the case of a thermometer, "Error at 98° C. is $\pm 0.6^\circ$, to an accuracy of $\pm .1^\circ$," means that the reading may be incorrect (either greater or less than the true amount) by an amount not more than .1° C.; in other words, the true reading lies between 98.5° and 98.7° C.

SUB-STANDARDS

Sub-Standard Instruments

Some of the check methods which have been described above involve the use of another instrument (a sub-standard) known to be reasonably accurate. It cannot be too strongly emphasized that any sub-standard instrument (especially an altimeter or air speed indicator) should be most carefully handled, and never on any account used for any other purpose. A sub-standard instrument should be allowed a period of rest, say twenty-four hours before it is again used. Sub-standards should be tested periodically (say every three months) in a properly equipped testing laboratory furnished with ultimate standards. The check methods are to be regarded only as emergency methods to be employed when proper testing plant is not readily accessible.

APPENDIX II

ERRORS AND CORRECTIONS

THE difference between the terms "Error" and "Correction" applied to instruments is not always clearly understood.

The error is the difference between the observed reading and the true reading. If a gauge is tested against a master-gauge which reads 120 lb. per sq. in., when the gauge under test reads 125, the error of the latter is said to be + 5. If the observed reading is less than the true reading, the negative sign is used.

The correction at any point of the scale is the amount which must be added (algebraically) to the observed reading to obtain the true reading. In the above case, the correction to be applied to the observed reading 125, to obtain the true reading 120, is - 5, because - 5 has to be added to 125 to obtain 120. The correction is positive if added (numerically), and negative if subtracted.

Thus, the correction is always of opposite sign to the error, but is referred to the *observed* reading, whereas the error is referred to the *true* reading.

In the case quoted above—

(a) The error at 120 is + 5.

(b) The correction at 125 is - 5.

If the gauge had read 115 for a true pressure of 120, the error at 120 would have been - 5, but the correction to be applied to the observed reading 115 would be + 5.

APPENDIX III

LUMINOUS COMPOUND AND ITS APPLICATION

LUMINOUS compound consists of zinc sulphide suitably prepared and mixed with radium salt as short a time as possible before the compound is required for actual use. The luminous effect is produced by the action of Alpha rays, emitted by the Radium, on the particles of zinc sulphide.

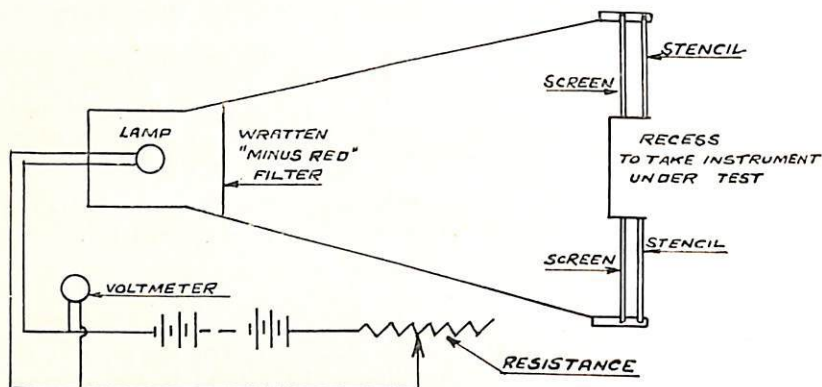
APPARATUS FOR TESTING LUMINOUS DIALS¹

FIG. 60

Mesothorium or a mixture of mesothorium and radium is sometimes used instead of radium.

When applying the compound, care must be taken to ensure that the surface to be luminized is free from grease and has a matt finish. The markings to be luminized are prepared with a coat of zinc white paint (free from lead) evenly applied and allowed to dry, before a coating of copal varnish is applied freely over the surface to be luminized. While this coat is still tacky, the luminous compound is applied over it by means of a pointed piece of pegwood. The luminous compound is prepared by mixing with gum arabic solution (1 oz. to 1 pint of water) to the consistency of cream.

When mesothorium is used the markings, after luminizing, should have a luminosity of at least 40 per cent of the N.P.L. Standard which is .015 equivalent ft. candles, i.e. 80 per cent of the R.A.F. Standard, which is .0075 equivalent ft. candles.

¹ In this diagram, each stencil and screen should be tilted so as to be normal to the line joining the centre of the lamp to the centre of the screen.

LUMINOSITY TESTS

Tests on luminosity are carried out by a comparative method developed at the National Physical Laboratory.

Light from a standard lamp placed at the end of a box passes through a Wratten (minus red) filter, and falls on two translucent diffusing screens at a distance of about 3 ft. from the source as in Fig. 60. In front of these screens are placed stencils so cut that the emergent light corresponds to the luminous markings of the instrument under test, which is placed in the recess between the stencils.

The current passing through the lamp can be varied by a rheostat in the circuit, and a voltmeter records the voltage across the terminals of the lamp.

Previous to testing, instruments should be kept in the dark for a few hours. Exposure to light causes a temporary increase in luminosity and it is essential that measurements be made under similar conditions.

During a test, the illumination of the stencils is gradually raised by cutting out resistance on the rheostat until the light emitted matches the luminized markings on the instrument. With a little practice, the matching point can be determined with reasonable accuracy. The reading of the voltmeter is then taken, and the luminosity figure is obtained from the table provided by the National Physical Laboratory, where the apparatus must have been previously calibrated.

APPENDIX IV

VIBRATION TESTS

It cannot be too strongly emphasized that the instruments used in aircraft are necessarily of a highly specialized nature. They are specially designed to stand up to very severe conditions of service. They are subjected not only to continual vibration during the whole time the engine is running, but to severe shocks in landing and when taxi-ing over the ground. They are expected to function whatever the position of the aircraft, to withstand reduced pressures at high altitudes, as well as a range of temperature altogether unusual in instruments used for any other purpose.

By placing one hand lightly on the instrument panel when the aircraft is taxi-ing over the ground, or during flight when the engine is running, the type of vibration to which the instruments are subjected may be realized. It will be found to be much greater than would be anticipated by anyone who has not made the experiment. It is not possible to eliminate all the effects of jolts and shocks and vibration, but they may be much reduced by the use of shock absorbers, spring mountings, and felt or horsehair insulation. It is important that these anti-vibration devices should be effectively fitted.

Vibration tests were instituted in order to reproduce vibrations of the same character as those likely to be experienced in aircraft. The intensity of vibration actually obtainable is greater than is met with in actual practice, but not such as to throw undue strain on the instruments under test.

It is a definite requirement in all the Civil Aircraft Specifications that instruments shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect the readings, impair the accuracy, or cause undue wear. All pins, screws, nuts, etc., must be secure against working loose under vibration. This necessitates the careful balancing of all the moving parts (to prevent excessive pointer oscillation), and the secure fixing of all adjustable parts, pins, screws, etc., so as to prevent any parts working loose. Vibration tests should also reveal any weakness which would cause failure due to breakage.

The tests are conveniently carried out on a specially constructed vibration table. The instruments are mounted on the panel and firmly secured in position by clips. The panel is rotatable between two uprights, and can be secured by wing nuts in a position inclined at any angle to the horizontal. The uprights are fixed to an horizontal board mounted on four springs anchored to a rigid base. In a central aperture of the panel, an eccentric weight, set in a suitable frame, can be caused to rotate by a flexible shaft, driven by an electric motor, of which the speed can be controlled by an adjustable resistance. The frame carrying the weight can be turned so that the weight can be rotated in a plane inclined at any desired angle to the instrument panel. The magnitude of the turning weight and its position on the radial arm can be varied, so that when rotating at 1,800 r.p.m., in the same plane as the instrument dials, the amplitude of the instrument panel is approximately 0.03 in. The amplitude can be judged by fixing strips of paper to the panel in two directions at right

angles. Small circles and spots of suitable sizes are marked on the strips. Under the conditions stated above, the spots will appear to describe circles, indicating that the vibration is circular in form. For any one position of the weight and a given speed of rotation, the amplitude will depend on the total mass of the instruments and panel. The amplitude should therefore be checked, when different types of instruments are under test. The panel should be uniformly loaded with four instruments, or if

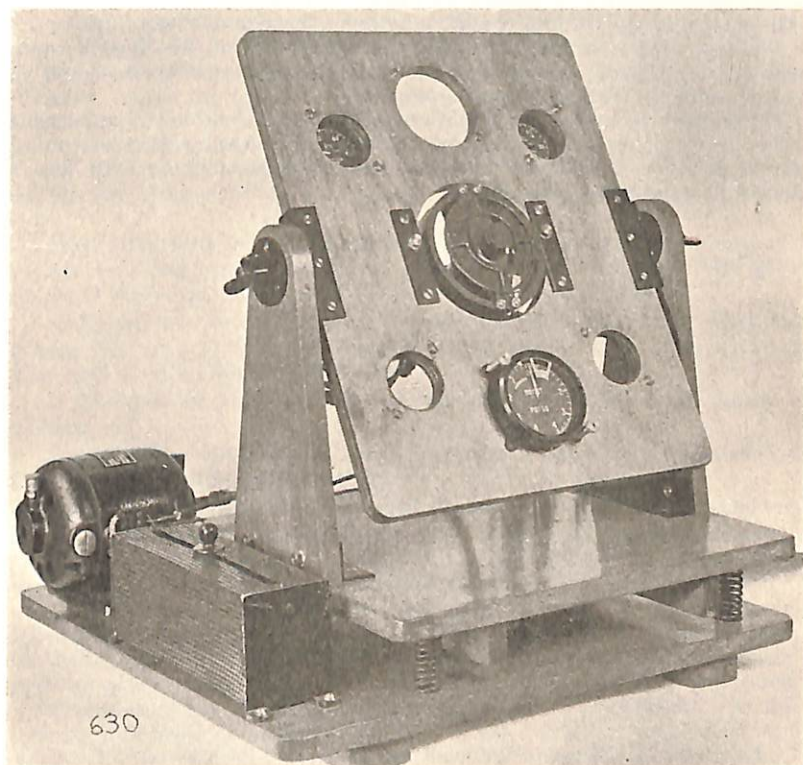


FIG. 61. VIBRATION TABLE
(Negretti and Zambra)

less than four are tested at a time, their equivalent in mass. It is important that the rotating weight should be perfectly free to rotate, as undue friction will radically alter the character of the vibration. If plain bearings are used, they must be kept well lubricated.

Tests should be carried out systematically in the following order—

1. With the dials in a vertical plane, and the frame of the "weight" adjusted so that the weight rotates in a plane parallel to the dials, the frequency should be varied from 1,200 to 2,200. The instruments should be caused to function over their complete range, and the behaviour of the pointer observed throughout the tests over a period of at least 10 min. Frequencies which give rise to resonance should be avoided.

2. The test should be repeated with the complete panel still vertical, but the weight adjusted to rotate in an horizontal plane.

In the above tests, the maximum amplitude is obtained by allowing the panel to vibrate freely. By gripping the panel with the hands the form and amount of the vibration can be varied. It is desirable to vary the vibration in this way in testing sample instruments of new design.

3. With the dials vertical and the weight rotating on a plane parallel to them, and at a frequency of 1,500 and amplitude of 0.03 in., a prolonged test is carried out over a period of at least 20 hours.

4. The test should be repeated after adjusting the plane of rotation of the weight to a position at right angles to the plane of the dials.

The last two tests are primarily for robustness of the design, and a check of the calibration should be made on completion of the test and the results compared with its previous record.

If carefully carried out, vibration tests yield valuable information as to the causes of pointer oscillation, unbalanced parts, insufficient control, and, if present, points of weakness and careless workmanship due to insecure fixing of pins and screws.

APPENDIX V

HIGH AND LOW TEMPERATURE TESTS

In addition to the tests on instruments at normal room temperature, tests at high and low temperatures are often desirable. Instruments may be required to function without permanent derangement in tropical climates, where the temperature may rise as high as 60°C . On the other hand, they are frequently exposed to extreme cold at high altitudes, where the temperature may fall in exceptional circumstances to -60°C . In the case of civil aircraft, however, the lower limit of temperature is seldom less than -20°C ., and instruments are normally tested to -5°C . only.

The behaviour of instruments at temperatures above and below normal is, therefore, a matter of considerable importance. The general effects of a change of temperature may be summarized thus—

1. Expansion or contraction of parts affecting clearances, thus introducing friction. A low temperature may cause a cover glass to become loose and even to fall out of the bezel.

2. Changes of elasticity, as in the case of metal diaphragms and springs.

3. Changes in viscosity of lubricants, where they are employed, introducing friction at low temperatures.

The tests at temperatures above and below normal involve the use of elaborate apparatus usually found only in a well-equipped laboratory. Full details cannot be given here, but the following brief particulars will give some indication of the methods commonly used.

Tests at temperatures above normal are usually carried out in some form of chamber (such as an incubator) in which the temperature can be controlled within definite limits by means of a thermostat. The chamber may be fitted with a tray of water and the humidity also controlled by a hygrostat, thus reproducing humid tropical conditions. A fan is necessary in order to keep the air within the chamber circulating, and to ensure that the whole volume of air is at the temperature indicated.

Low temperature tests are usually carried out in a chamber, the air in which is maintained at a temperature below 0°C . by means of a refrigerant circulating in piping round the air space. Carbon-dioxide is often used for the purpose. The gas is liquefied by a compressor plant at a pressure equal to about 70 atmospheres, and then passed through a series of pipes, surrounded by a water-jacket, and constituting a condenser system. The liquid CO_2 passes from the condenser through a regulator (which regulates the pressure) into the evaporator, where evaporation takes place. During this process, the heat required for the change, liquid to gas, is abstracted from the lagged chamber through which the evaporator coils pass. After evaporation, the gas returns to the compressor to undergo re-compression and subsequent liquefaction and evaporation. The cooling process is therefore cumulative. The cycle of operations is continuous and the same gas is used repeatedly. For testing small numbers of instruments for civil aircraft a "Frigidaire" or other similar plant may be used, and on a small scale the use of a simple freezing mixture is suitable.

INSTRUMENTS

FREEZING MIXTURES

Composition (by Weight)		Reduction of Temperature obtainable, ° C.	
Ammonium Nitrate .	1	}	25
Water	1		
Sal-ammoniac . .	5	}	22
Ammonium Nitrate .	5		
Water	16		
Snow or pounded ice .	2	}	22
Common Salt . . .	1		
Snow or pounded ice .	12	}	31
Common Salt . . .	5		
Ammonium Nitrate .	5		
Snow or pounded ice .	2	}	45
Calcium Chloride . .	3		
Snow	3	}	30
Dilute Sulphuric Acid .	2		

Of these, ice and salt is the cheapest and has a greater thermal capacity than mixtures not containing ice, that is to say, the quantity of heat absorbed is greater than in the case of equal weights of other mixtures. This is due to the greater latent heat of fusion of ice. It should be clearly understood that the temperature obtained is no guide as to the quantity of heat absorbed.

Small amounts of solid carbon-dioxide can be obtained from the ordinary CO₂ cylinders by tying a flannel bag two or three layers thick over the exit nozzle of the inverted cylinder and opening the valve. The solid CO₂ snow collects in the bag. Its temperature is about - 90° Cf. and it is soluble in methylated spirit, so that by dissolving suitable amounts in a quantity of the spirit the resultant temperature of the solution can be regulated.

In using freezing mixtures, care must be taken to prevent any part of the instrument coming into direct contact with the constituents of the mixture.

A temperature of - 60° C. is most conveniently and quickly obtained by using liquid oxygen, which is allowed to boil off and circulate through the cooling coils surrounding the chamber. In all cases, it is essential to ensure by means of a fan (or by constant stirring in the case of liquids) that the air or liquid is kept circulating, and to allow the instruments under test to "soak" for a period of 20 min. or half an hour to ensure that all parts attain the temperature measured by the thermometer, which forms part of the equipment.

The errors permissible at low temperatures are greater than those allowed at normal temperatures, and reference should be made to the relative specification for information on this subject.

One particular application of a low temperature test may be noted here. The only method of ascertaining whether a radiator thermometer (see p. 24) filled with ethyl-ether or some similar liquid is correctly filled

is to apply a low temperature test. The system should contain only ethyl-ether liquid and its vapour. If carelessly filled, residual air or moisture may be present, the effects of which become apparent when the gauge and capillary are cooled to a temperature below freezing-point, while the bulb is at a temperature of between 60° and 70° C. The presence of air will be indicated by much lower readings than those obtained at normal temperature. Moisture in the form of water or water vapour will freeze in the tube, and, as a result, the instrument will cease to function.

A testing cabinet for high and low temperature tests with a range from $+60^{\circ}$ to -60° C. has been produced by the "Korect" Depth Gauge Co. The refrigerating agent is solidified CO_2 , which can be readily and cheaply obtained under the trade name of "Dry Ice," and is handled without danger, provided rough leather gloves are worn. The cabinet is carefully insulated and the central metal chamber is capable of accommodating six air speed indicators of the usual size, and thermometers for observation of temperature. The central chamber is enclosed with a plate-glass lid and along each of its sides, external to the chamber, run metal galleries on which the refrigerant, in the form of small lumps, is placed.

With this apparatus the temperature of the inner chamber can be reduced to -20° C. in about 30 minutes, and maintained at this temperature for at least half an hour. Further reduction of temperature to -60° C. can be obtained by removing the lid, repacking the galleries with the refrigerating agent, and closing down for about three-quarters of an hour. This temperature may be maintained by occasional additions to the refrigerant.

A separate insulated chamber is used to store the solidified CO_2 and is fitted with a coil system, so that it can be used as an auxiliary to the cabinet, when a low temperature has to be maintained for several hours.

Provision is made for carrying out high temperature tests in the same chamber by means of heating lamps, a temperature of $+50^{\circ}$ C. being obtained in about 40 minutes. Special drying cells are provided. An air fan, rotated by a small motor mounted outside the cabinet, keeps the air in the chamber in circulation and at an approximately uniform temperature.

In all cases, an instrument should be allowed to remain in the hot or cold chamber at least twenty minutes before any readings are taken. This will ensure that the whole instrument is brought to the temperature of the chamber.

A drying tunnel is a useful additional piece of equipment and avoids the possibility of damage to instruments through condensation of moisture inside the case. The tunnel is approximately 4 ft. in length and a foot square in section. A suction fan at one end draws air through the instruments placed in the tunnel. The air is heated by four electric lamps at the other end and dried by passing through a double screen shutter containing silica gel.

*APPENDIX VI

THE ISOTHERMAL AND I.C.A.N. CONVENTIONS

THE limitations of the aneroid type of altimeter as a height measurer have already been pointed out (see p. 50). The instrument has to be calibrated on some agreed basis as to the variation of pressure with height. The temperature at different heights is continually changing and no assumptions can be made which apply strictly to the actual conditions at the time of observation. The readings of the altimeter must therefore be corrected for temperature if a reasonably correct estimate of height is desired. The temperature of the air is measured by a special type of thermometer, fitted to a strut (see p. 28) and the observed reading is used to correct the reading of the altimeter (calibrated isothermally) by means of a Computer (see p. 100). There are two methods of calibrating altimeters.

The Isothermal Convention

This assumes that the temperature at all heights is constant and 10°C ., and that the pressure varies with the height according to the formula—

$$H = 62.580 \log_{10} \frac{P_0}{P}$$

where H = height (thousands of feet)

P = pressure at height H

P_0 = the ground pressure.

The I.C.A.N. Convention

The International Commission for Air Navigation adopted a convention which takes into account variations of temperature with height, as explained on p. 34. It is assumed that the temperature falls uniformly at the rate of 1.98°C . per 1,000 ft. from 15°C . at ground level to -56.5°C .

Note. STANDARD GROUND PRESSURE is taken as that due to a column of mercury 760 mm. **29.921 in.** in height at 0°C in Latitude 45° . Mercury under these conditions is referred to as "Standard Mercury." It is necessary to specify the temperature and latitude, since the density (and therefore the weight) of a column of mercury varies with these conditions.

Another unit, the millibar, is now commonly used, in meteorology. **The millibar** is one-thousandth part of the **BAR**, which is a unit of absolute pressure, equal to 1 megadyne per sq. cm. Thus 1 millibar = 1,000 dynes per sq. cm.

Standard Ground Pressure, namely, 760 standard mercury millimetres (or 29.921 standard mercury inches), is equal to **1013.2 millibars**. This is the standard ground pressure according to both the isothermal and I.C.A.N. conventions. Previous to the introduction of the I.C.A.N. Convention, standard ground pressure was taken as **29.90 mercury-inches**.

Under **London Laboratory Conditions** (16.6°C . or 62°F ., Latitude $51\frac{1}{2}^{\circ}$, standard ground pressure is **29.994 mercury-inches** (761.62 mercury-millimetres).

A standard mercury column can be graduated to read inches, millimetres, millibars, or equivalent heights, (according to either the isothermal or I.C.A.N. convention). It is usual to graduate the brass scales to read true inches (or mms.) at 16.6°C .—the standard temperature of the Imperial Standard Yard. If used at any other temperature, a correction must be applied. At 0°C . in Latitude 45° a pressure of 1013.2 millibars would be indicated by a reading **29.930 in.** and not 29.921.

at 36,090 ft.; and that above this height (namely, in the stratosphere) it remains constant at -56.5°C . This is not necessarily the most accurate relation between temperature and height, but it does represent approximately the general average conditions all over the world and is a great improvement on the Isothermal convention which assumes a constant temperature of 10°C . ($283^{\circ}\text{Absolute}$) for all heights.

The I.C.A.N. convention is as follows—

P_0 = ground pressure in millibars (taken as 1013.2 mbs.)

P = pressure at height H in millibars

H = height in thousands of feet

P_1 = pressure at 36,090 ft. calculated from the formula—

$$\frac{P_0}{P} = \left(\frac{288}{288 - 1.98 H} \right)^{5.256}$$

which holds for heights up to 36,090 ft. For heights above this figure the formula:—

$$H = 36,090 + 47,900 \log_{10} \frac{P_1}{P} \text{ is used.}$$

These formulae are based on the assumption that for heights between ground level and 36,090 ft. the temperature is $15 - 1.98 H$, and that for heights above 36,090 ft. the temperature is constant and equal to -56.5°C .

From the formula quoted above, tables can be drawn up showing the relation between: (a) the height, (b) the equivalent barometric pressure at that height, and (c) the temperature at that height, according to the I.C.A.N. convention (see Cols. 1, 2, and 3 in the table, p. 98). By means of these tables an altimeter can be calibrated directly in terms of height.

The equivalent barometric pressures in Col. 2 are calculated for London Laboratory Conditions. The permissible errors for various ranges are shown in Cols. 4, 5, 6, and 7 of the table.

It must be emphasized again that these "Permissible Errors" are those allowed under the standard conditions of test, namely, a reduction (or increase) of pressure at a rate equivalent to an ascent (or descent) of 1,000 ft. per minute. They include the "lag" (see p. 48).

Calibration of an Altitude Recorder

As an illustration of the method of using these figures, the calibration of an Altitude Recorder to the I.C.A.N. scale will now be considered. The instrument has to be calibrated to indicate the heights shown in Col. 1 at the barometric pressure in Col. 2 and the temperature in Col. 3 (p. 98).

In practice the temperature may be within 10° of the value in Col. 3, except at zero height, when this figure is taken at 20°C . (namely, -5°C . to $+35^{\circ}\text{C}$. diminishing *pro rata* to 10°C . at a height of 5,000 ft.

Now it is not an easy matter to adjust the conditions of pressure and temperature, exactly to the figures given in successive lines of Cols. 1, 2 and 3 of the Table, so that the heights recorded on the chart of the instrument can be compared with the values in Col. 1 and the errors noted. A simpler procedure will now be described, the figures being taken from an actual test report.

Two series of readings, one at room temperature (say 21°C .) and the other at a lower temperature (say -25°C .) are taken and the results tabulated. See Cols. A and B in Table on p. 99. The difference in the readings

TABLE OF PRESSURES AND TEMPERATURES AT THE HEIGHTS GIVEN IN COLUMN 1
(I.C.A.N. CONVENTION)

1	2	3	4	5	6	7
Height thous. of ft.	Press. Inches of Mercury at 16.6° C. and at latitude 51½°	Temp. Centigrade	Approx. Permissible Errors in Feet			
			Range to 10,000 ft.	Range to 20,000 ft.	Range to 30,000 ft.	Range to 40,000 ft.
1	31.09	17.0	35	140	200	270
0	29.99	15.0	40	150	210	280
1	28.93	13.0	45	160	220	290
5	24.96	5.1	65	200	260	330
10	20.63	- 4.8	90	250	310	380
15	16.93	- 14.7		300	360	430
20	13.78	- 24.6		350	410	480
24	11.63	- 32.5			450	520
30	8.91	- 44.4				580
40	5.55	- 56.5				680

	A	B	C	D	E	F	G	H	I
Temp.	21° C.	- 25° C.	Difference for 46° C.	Difference for 1° C.	I.C.A.N. Temp.	Temp. Diff. from I.C.A.N.	Difference for I.C.A.N.	Calibration for I.C.A.N.	Correct for Zero
Baro. Equiv.	- 180 ft.	280 ft.							
1,000 of ft.	ft.	ft.	ft.	ft.	°C.	°C.	ft.	ft.	ft.
Up. 0	Nil	- 70	- 70	- 1.52	15	6.0	- 10	- 10	Nil
5	- 50	- 160	- 110	- 2.39	5.1	15.9	- 40	- 90	- 80
10	- 30	- 160	- 130	- 2.83	- 4.8	25.8	- 75	- 105	- 95
15	+ 10	- 120	- 130	- 2.83	- 14.7	35.7	- 100	- 90	- 80
20	Nil	- 180	- 180	- 3.91	- 24.6	45.6	- 180	- 180	- 170
Down 15	+ 80	- 170	- 250	- 5.43	- 14.7	35.7	- 195	- 115	- 105
10	+ 50	- 160	- 210	- 4.57	- 4.8	25.8	- 120	- 70	- 60
5	+ 10	- 150	- 160	- 5.48	5.1	15.9	- 55	- 45	- 35
0	+ 40	- 50	- 90	- 1.95	15.0	6.0	- 12	+ 28	+ 38

for the change of temperature (i.e. 46°C.) is recorded in Col. C, from which can be calculated the difference in reading (feet) per degree C. change of temperature—Col. D. The readings at the corresponding I.C.A.N. temperatures can now be calculated by proportion.

The I.C.A.N. temperatures are set out in Col. E of the Table. The differences between these temperatures and the room temperature (i.e. 21°C.) are set out in Col. F and the corresponding height—differences in Col. G are calculated by multiplying the figures in Col. D by those in Col. F. Adding the results to Col. A, we obtain the calibration figures for the I.C.A.N. scale of temperature (Col. H). Correction for zero can be made by adding 10 to each figure in turn and thus obtaining Col. I which gives the reading at each height at the temperature specified by the I.C.A.N. relation for that height.

The reader who wishes to gain a clear understanding of the principles and methods involved in the determination of height and the calibration of altimeters is urged to work through the above calculations. The subject is an intricate one and must be carefully studied if a thorough grasp is to be attained.

The Computer consists of a circular flanged base plate approximately 6 in. in diameter, on the rim of which are engraved two scales, one of temperature, the other of height. A second concentric disc of smaller diameter, carries logarithmic scales of height and air speed and can be rotated relative to the larger disc by means of a milled head at the centre.

The instrument is used to obtain corrections to the readings of either the altimeter or the air speed indicator. Adjustable interlinked pointers can be set to the readings of the air thermometer and altimeter (or air speed indicator) and the corrected values are read off on the appropriate scales.

If a Computer is not available, corrections may be applied to the readings of an altimeter, calibrated according to the isothermal convention in the following way—

During a climb to height H as indicated by the altimeter, the air temperature t is observed at some intermediate height H_t as noted on the altimeter. H_t should not be near ground level, where large variations of temperature may occur. The correction to be applied to the reading at H is given by the formula—

$$\text{Correction} = 1,000. H\{0.0031 (2H_t - H) + 0.0035 (t - 10)\}\text{ft.}$$

H and H_t being in thousands of feet.

The reader should apply the formula to show that the correction at 30,000 ft. is - 2,220 ft. when on the climb the air temperature was -20°C. at 20,000 ft.

The correction to be applied to an altimeter calibrated to the I.C.A.N. convention may be obtained from the corresponding formula—

$4(2H_t + T - 15) H$ ft., which applies only up to 36,090 ft. In the case cited above, the correction will be found to be 600 ft. instead of - 2,220 ft.

*APPENDIX VII

THE GYROSCOPE¹

THE principle of the gyroscope enters into the design of several types of turn indicators and as its behaviour presents considerable difficulty, a brief description of the phenomena is given here. A complete explanation involves considerable knowledge of mathematics.

Consider a wheel (having for its size a very heavy rim) free to spin about its axle (Fig. 62A). Suppose it is caused to spin rapidly. We find that it offers considerable resistance to any attempt to change its speed of rotation. This is easily proved if an attempt is made to grip the rim. Consider a small portion of the wheel at P of mass m at a distance r from the centre O . P is constrained by the rotational motion to move in a circle (radius r) with velocity, say, V and is therefore subject to a force F (centripetal force) directed inwards towards O .² Regarding the rim as composed of a large number of small masses such as m disposed as the links of a chain, maintained in a rapid circular motion, each is acted upon by tensions T, T due to its neighbours. These tensions act at a very small angle to one another and are of considerable magnitude. The unresolved parts along the radius constitute the force F . Any attempt to deflect the mass at P from its circular path will meet with great resistance, as it will be necessary to overcome the resolved parts of these tensions which would immediately be brought into play.

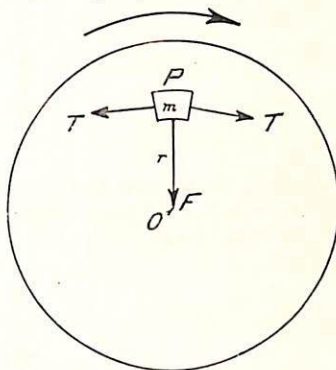


FIG. 62A

Further, the spinning wheel offers great resistance to any attempt to change the direction of its axis. This can only be brought about by applying twisting forces, constituting a **Torque**. The torque is measured by the moment of the forces about the axis of twist.

Suppose that, while the wheel is spinning about the axle WE , the axle itself is rotating in space (about a vertical axis perpendicular to the plane of the diagram) so that it occupies successively the positions $W_1 E_1$, WE , and $W_2 E_2$ (Fig. 62B). Such a rotation is called a precessional motion. The axle is said to precess about the axis of precession, which, in this case, is perpendicular to the plane of the paper.

The forces which would produce such a **Precession** will now be considered. Let P be a point on the edge of the rim of the wheel above the plane of the paper. When the axis is in the position WE , P lies in the meridian. A moment earlier, when the axis was in the position $W_1 E_1$, P was to the east of the meridian. A moment later, the axis occupies the

¹ *Spinning Tops and Gyrostatic Motion*, by H. Crabtree is recommended for the student. A popular account is given in *Spinning Tops* by Perry (Romance of Science Series).

² For proof, see any textbook on Dynamics.

position $W_2 E_2$ and P is still east of the meridian. The path of P is therefore a curve $P_1 P P_2$. Thus P is acted upon by a force eastwards. Similar

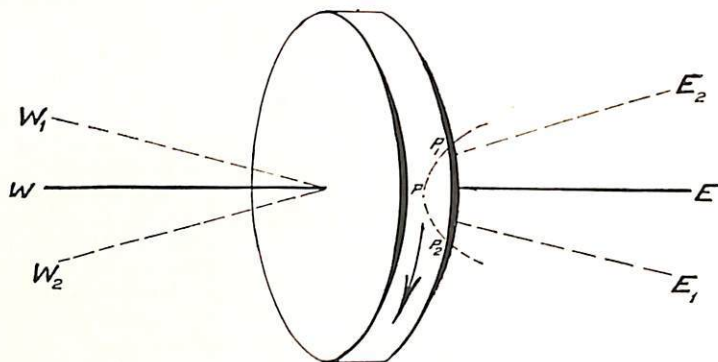


FIG. 62B

reasoning shows that the corresponding point on the other side of the rim describes a curved path concave to the west, and is therefore acted upon by an equal force to the west. These two equal and opposite forces con-

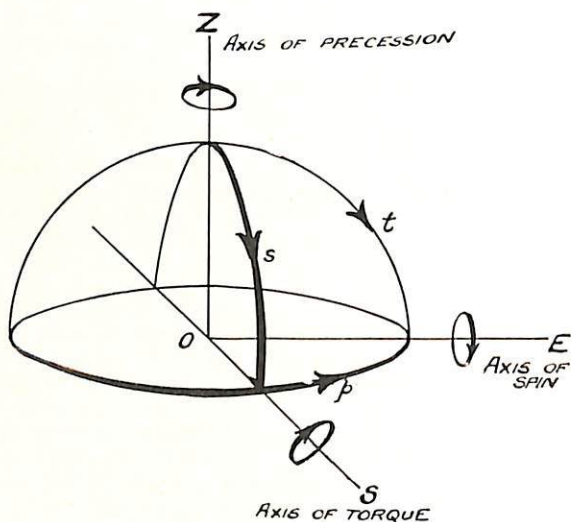


FIG. 62C

stitute a twisting movement or torque tending to twist the wheel about SO . The direction of this torque is right-handed as seen from S . Thus a torque tending to twist the wheel about the axis ON , produces a precession in the direction of a right-handed screw about the axis OZ (Fig. 62E).

Such a torque could be provided by a weight applied to the E end of

the gyro axle. This would cause the gyro to precess about an axis at right angles both to the spin axis and the torque axis.

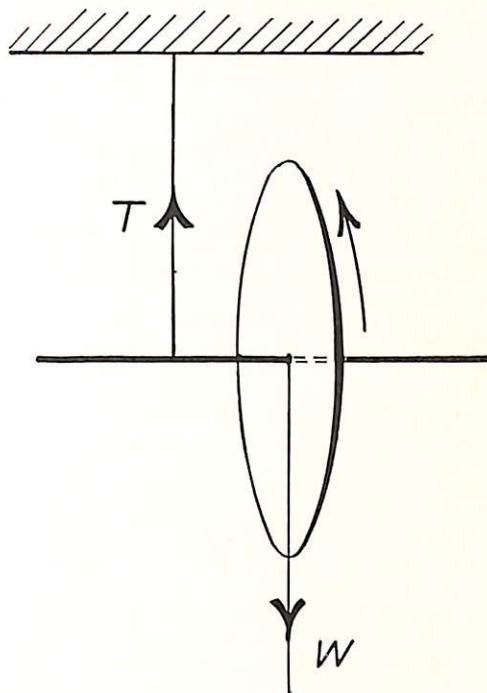


FIG. 62D

A similar effect can be observed if a cycle wheel is suspended by a cord attached to a point on the axle. So long as the wheel is at rest it cannot

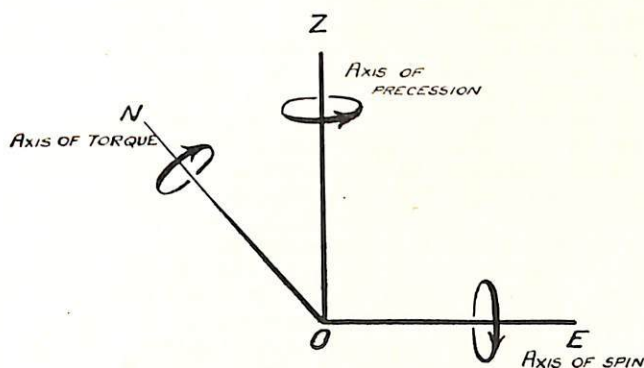


FIG. 62E

maintain the position shown in Fig. 62D without additional support. If it is made to revolve, it is capable of maintaining its plane of revolution

vertical. It will be seen, however, that the axle revolves slowly in azimuth, namely in a horizontal plane. This is the precessional motion due to the action of the torque produced by the equal forces, T the tension in the cord and W the weight of the wheel.

The three axes of spin, torque, and precession are mutually at right angles and the directions of rotation are those of right-handed screws along the axes OE , ON , and OZ (Fig. 62E).

To sum up: The direction of the axis of a free gyro remains fixed in space provided the forces acting do not produce a torque about its centre of gravity. If such a torque is produced and its axis is not parallel to the spin axis of the gyro, the effect of the torque is to cause a change in the direction of the gyro axis. The resulting angular motion of the gyro axis is called **Precession**.

It should be noted that if at a point O the axes of spin and torque are set out at right angles as at OE and ON , the axis of precession OZ is at right angles to both, and the direction of the precessional turn is such as to rotate the axis of spin towards the torque axis by the shortest route.

*APPENDIX VIII

HASLER TEL INDICATOR AND RECORDER

THE mechanism of the Tel Indicator and Recorder is very ingenious, and the reader who has an opportunity of examining the action when the cover is removed should be able to follow the sequence of operations with the assistance of the following notes.

The flexible shaft is connected at one end to some convenient rotating part of the engine (usually the camshaft drive); and at the other end to the vertical spindle extending through the bottom casing. At its upper end the spindle 1 carries a bevel-wheel, which engages the bevel wheels 2 and 3 mounted on the shaft 4 (Fig. 64A). This shaft rotates in one direction only, irrespective of the direction of rotation of the vertical spindle, the wheels 2 and 3 being connected to the shaft by keys and springs forming a ratchet drive. The shaft 4 drives the spindle *II* by suitable gearing. On the spindle *II* are fixed three segments (k_1), having on one side ratchet teeth, which can engage—or clear—corresponding teeth on three loose discs (*k*). The arrangement constitutes a set of three positive-drive clutches.

The spindle *II* is shown with the associated mechanism in greater detail in Fig. 64B. The pinion *r* is attached to the loose disc *k* and both can be moved along the spindle by the lever *H*, which is actuated by a conical-faced cam mounted on the spindle *I*, driven at constant speed by clock-escapement mechanism. There are three such cams in the spindle *I*, one for each of the three clutches. Each cam has two sets of notches; formed at different radii as shown in Fig. 64C. The cams are positioned on the spindle *I* so that the notches on any one cam are displaced by 60° in relation to those on the other cams. As the spindle *I* rotates, the roller *A*, at the end of the lever *H*, under the action of a spring (which keeps it in contact with the cam) slips into one of the notches, thus engaging the two parts of the corresponding clutch and causing the pinion *r* to drive the wheel *Z*, which rotates freely on the spindle *III*. As *Z* rotates, the projection *m* on its rim engages the stirrup *U* carrying the pointer *P* of the speed indicator. The pointer is thus carried round to an extent depending on the speed of shaft *III*, and on the time the two components of the clutch are in engagement. The time of engagement is determined by the speed of shaft *I* and by the shape of the cam, and these are arranged so that the clutch is closed for exactly one second. Thus the pointer is rotated through an angle directly proportionate to the speed of rotation of the spindle *II*, and therefore to the engine speed.

At the end of one second, the cam moves the lever *H* and the clutch is disengaged. The stirrup would then fly back to its original position under the action of a spring, but for the effect of a second lever *H*₁ (see Fig. 64B). A conical roller *B* on the upper end of this lever works against an inner face on the cam, in which there are two outer notches at right angles to those on the outer face of the cam. At the lower end of the lever a toothed block *B*₁ is mounted. At the end of the first second the clutch parts are released and the block *B*₁, actuated by the movement of the lever *H*₁, holds *k* (and therefore *r*, *Z* and *U*) stationary for another second, at the end of which time *k* is released and *Z* returns to its original position during the

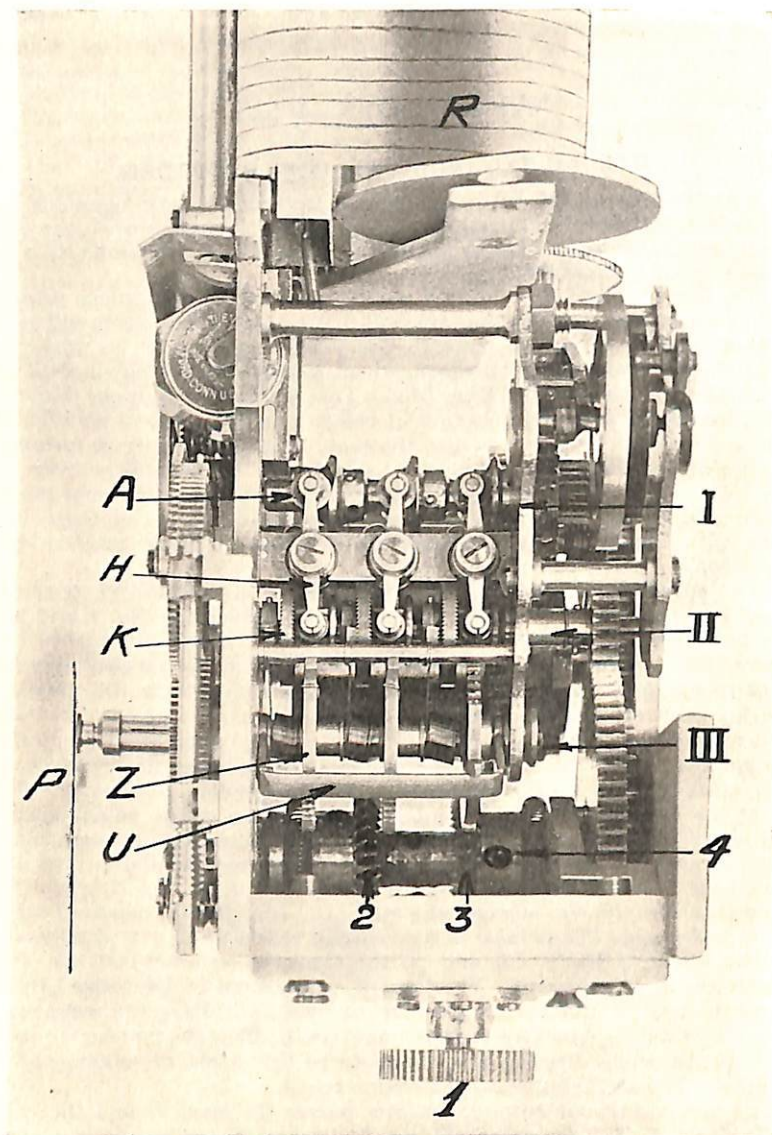


FIG. 63. HASLER TEL INDICATOR (CASE AND CLOCK REMOVED)

third second. The stirrup *U* is common to all the three sets of cams and levers, clutches, and gearing. One set only is shown in Fig. 64B.

The cycle of operations is carried on by all three sets of cams, with a time displacement of one second. Each complete cycle occupies three seconds, and thus the instrument indicates each second the mean speed of the preceding second.

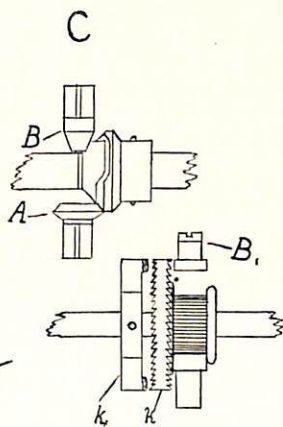
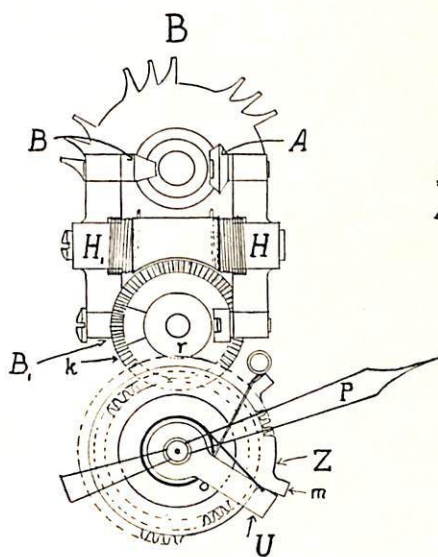
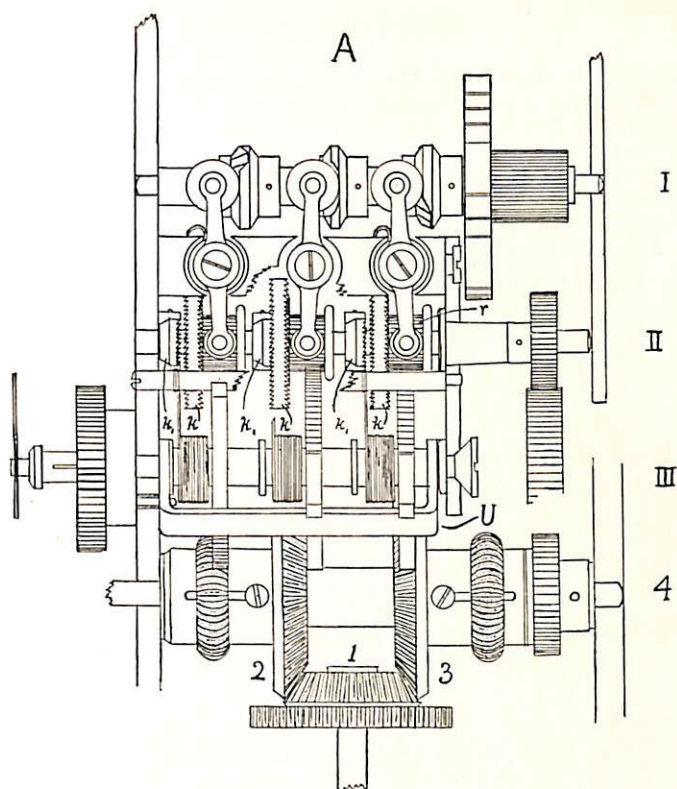


FIG. 64. TEL INDICATOR

The clockwork mechanism for driving the camshaft is wound automatically from the driving spindle approximately every two minutes. The winding gear is automatically disconnected when the spring is fully wound so that over-winding is prevented. The chart drums are driven by the same clockwork mechanism as the camshaft, the stylus being actuated by gears and rack mechanism from the spindle of the pointer.

The eight-day clock is a separate unit and is wound by hand. It actuates a second stylus, moving up and down vertically on the chart *R*, giving a

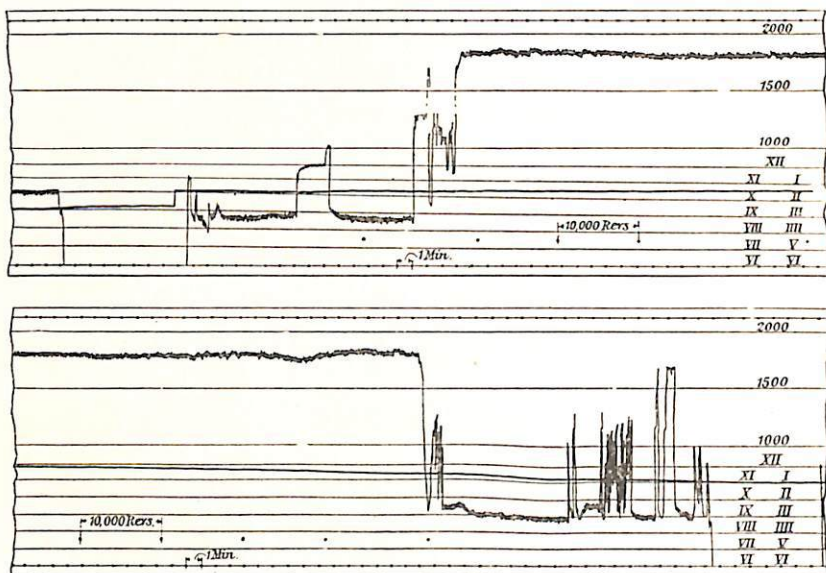
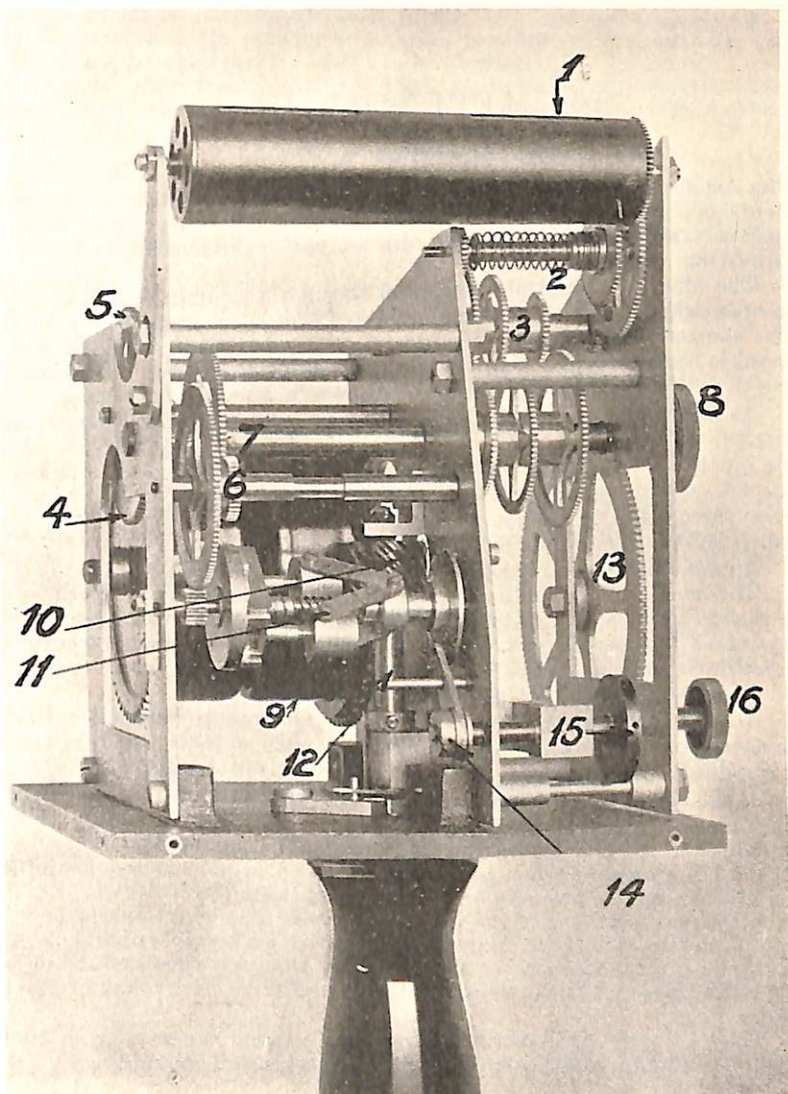


FIG. 65. PORTION OF CHART RECORD OF TEL INDICATOR

time record in the form of a line inclined upwards from 6 to 12 o'clock, and downwards from 12 to 6 o'clock. When the engine is not running, the paper is stationary and the time line is vertical as shown on the left-hand side of Fig. 65, indicating the fact that the engine was stationary for nearly half-an-hour before commencement of the flight. The small knurled knob near the right-hand corner is provided for setting the clock hands. The knob on the other side sets the counter to zero. The setting of the stylus is very critical, a small fraction ($\frac{1}{8}$ th) of a turn making the difference between a faint record and a torn chart. After adjustment, the stylus bar should be removed and the setting locked by means of shellac varnish.

The drum carries a length of paper sufficient for a record of 100 hours' flight. Portions of a chart record reproduced in Fig. 65 show the conditions of commencement and finish of a flight.



APPENDIX IX

THE ASHDOWN ROTOSCOPE

THE Ashdown Rotoscope is an instrument designed primarily for measurements of speeds of rotation. It can also be made to provide a "slow-motion" view of rapidly rotating objects, particularly useful in the study of moving machinery.

The object under study is viewed through a shutter, which is caused to open and close so as to give glimpses of the object at regular intervals. The shutter is actuated by a powerful spring-driven mechanism, and its speed is controlled by a 5-speed gearbox, giving the coarse adjustment of speed, with a fine-speed control by means of a balancing governor.

At the right-hand side of the box is a milled head (called the primary) marked with a red spot. This head operates the 5-speed gearbox by drawing out the sleeve to the required position *A*, *B*, *C*, *D*, or *E* marked on the sleeve, the ratios being 1, 2, 4, 8, and 16 to 1 respectively. Since for every revolution of the shutter one has two views of the object, these ratios must be again doubled.

An example of the rotoscope settings is given in the table (p. 111).

The smaller of the milled heads at the side of the case operates the governor, by means of which the primary can be set to run uniformly at any speed between 50 and 125 r.p.m., indicated by the figure seen in the aperture at the side of the instrument. The speed of the shutter is given by this primary speed multiplied by the gear ratio.

An unknown speed is determined by systematic alterations of the shutter-speed by means of the controller, until a clear stationary view is obtained. This requires a little practice, and full details, with tables to assist the observer, are given in the booklet provided with the instrument. The general principle of the "stationary" or "stroboscopic" view is explained in the chapter on Engine Speed Indicators (see p. 7).

Care is necessary when manipulating the gear setting to ensure that the gear wheels are properly in mesh, namely when the letter *A*, *B*, *C*, *D*, or *E* appears just clear of the side of the case. The gears should be "felt into mesh" by slightly turning the primary milled head to and fro.

If the shutter-speed is set slightly lower than the speed of the object, the latter appears to be in "slow-motion," useful for close study of moving parts.

The "C" type Ashdown Rotoscope has a speed range of from 800 to 6,000 per minute, and the speed is read directly from the scales.

Checking and Adjusting the Ashdown Rotoscope

A simple method of checking the Rotoscope is provided by a synchronous electric motor operated from the 50 cycle A.C. lighting mains. A motor designed to run at 1,500 r.p.m. will be found convenient, and the speed will be kept reasonably constant by the controlled frequency of the mains supply. To the motor shaft is attached a small white disc with a black spot painted near the rim. Suppose the spot rotates in a clockwise direction at 1,500 r.p.m. when the motor is running, it should appear stationary when viewed through the rotoscope set for 1,500 r.p.m. If the spot appears to rotate slowly in an anti-clockwise direction the shutter

of the rotoscope is rotating too fast. If the spot appears to rotate in a clockwise direction, the shutter is rotating too slowly. In each case the necessary adjustment can be made on the regulator.

When this adjustment has been made at 1,500 r.p.m., other shutter speeds can be checked as indicated in the following table. The settings apply to "A" type Rotoscope, for speeds up to 4,000 r.p.m.

ROSCOPE SETTING (Speed of Object 1,500 r.p.m.)

Gear	Primary speed	Shutter speed r.p.m.	Image appears
<i>B</i>	125	500	Single
<i>C</i>	93.75	750	Single
<i>C</i>	125	1,000	Double
<i>D</i>	93.75	1,500	Single
<i>D</i>	125	2,000	Quadruple
<i>E</i>	93.75	3,000	Double

The reader will find it a useful exercise to think out the reason for the appearance of the image given in the last column, as well as to verify the following formulae connecting N the frequency of the rotoscope shutter, and x the number of spots visible.

$$(a) \ x - \text{odd}; N = \frac{1500}{1 + nx}, \quad \frac{1500 \cdot x}{2 + nx}, \quad \frac{1500 \cdot x}{3 + nx}, \dots \frac{1500 \cdot x}{(n-1) + nx}.$$

$$(b) \ x - \text{even}; N = \frac{1500}{2n + 1}$$

n being any number 0, 1, 2, 3, . . . etc.

APPENDIX X

REPAIRS AND ADJUSTMENTS

THE extent of instrument repairs and adjustments which may be attempted by ground engineers depends entirely upon facilities available in the way of equipment and tools and the manipulative skill of the individual. Certain adjustments, such as the resetting of the pointer positions on most instruments, can be carried out with the aid of the simplest of apparatus, and the minimum of apparatus installed will depend on the extent of the work which it is intended to carry out. Instruments embody very delicate mechanism, and it is extremely easy to upset completely the accuracy and performance by neglecting a few simple precautions. The ground engineer should, therefore, provide himself in the first place with such small tools as will facilitate careful handling. The following are the minimum requirements—

- 2 clock screwdrivers (two sizes).
- 3 watchmakers' screwdrivers (three sizes).
- 2 pairs tweezers—one pair at least to be kept free from magnetization.
- 2 or 3 pairs of small pliers of various types.
- Set of small files.
- 1 small bench vice with clamps.
- 1 bunsen burner and small soldering iron.
- 1 pointer remover.
- 1 hand vice.
- Watchmakers' brushes, cleaning rags, etc.

The necessity for cleanliness must be emphasized. Filings and dirt left in an instrument may have serious consequences.

Much information on the characteristics of the various instrument mechanisms can be obtained from actually dismantling and reassembling. The reader is strongly recommended to take every opportunity of building up his practical experience by obtaining any old or discarded or scrapped instrument and endeavouring, by a close study of its various parts, to dismantle, clean, readjust, and recalibrate it. It may not follow that the instrument is rendered serviceable by this means, but a training is built up in this way which will assist in the handling of instruments actually required for service.

Where replacements of parts are necessary, involving highly specialized machine tools, it is desirable that the instrument should be returned to a recognized repair depot rather than time should be wasted in attempts at repair which at best can only produce a makeshift. If, on the other hand, makers are willing to provide spare parts for their instruments, and these are fitted by ground engineers, recalibration and/or re-ranging are invariably necessary. The importance of allowing an instrument to settle down or "normalize" after assembly and before recalibration cannot be over emphasized.

Before individual types of instruments are dealt with, the following general remarks should be helpful in enabling considerable instrument work to be undertaken by anyone with average skill.

In the first place, the ground engineer should provide himself with a bench which should be conveniently situated close to his test apparatus and in a good light. The bench should be covered with linoleum or oil-cloth, and should be kept free from dirt and filings. Suitable racks and holders should be provided for the orderly accommodation of tools, etc.

In dismantling an instrument, it is always advisable to study the mechanism and its adjustments before work is commenced. This precaution often saves time on reassembly. A small tray for screws and very small parts is necessary, and wide-mouthed glass jars with lids will be found useful. A dish of petrol should be at hand for the immersion of fouled and dirty parts. During dismantling a close watch should be kept for worn and strained parts, so that these may be replaced if necessary. The lubrication of instruments is a subject of special study, since the functioning of certain instruments is adversely affected at low temperature by the presence of oil where it is not intended that any should be applied. Gearboxes and ball-races of engine speed indicators should be greased with a special grease, but on no account should oil be applied to the surface of the centre spindle. This will inevitably result in excessive friction at low temperature. The altimeter should not be lubricated, but on the other hand special watch oil is very sparingly applied to jewel holes in watches and to the mainsprings. Therefore all parts, after immersing and washing in petrol, should be well brushed with a watchmaker's brush which has been kept free from grease and dirt.

Pivot and spindle holes should be cleaned with a piece of sharpened pegwood or wood with little grain.

Glasses. The face glass of an instrument is the part that most frequently requires replacement. The glass is usually fitted to an instrument in one of the three following ways—

- (a) The glass is held in position beneath a screw-on bezel.
- (b) A bevelled-edge glass is snapped into a recess in the bezel as in watches, altimeters, and some engine speed indicators.
- (c) The glass is retained by a spring ring snapped in place above it.

In every case the fitting of a glass should be carried out so that it is tight under vibration and not liable to fall out. If glasses are fitted as (a) the bezel must be tightened down on to the glass, paper washers being used if the new glass is thinner than the discarded old one. It is a good plan to accumulate a stock of instrument glasses of various sizes.

Pointers. It frequently happens that instrument pointers become loose or detached from their spindles in service. Although these may seem to have been replaced securely, they may work loose again subsequently. Pointer spindles are invariably tapered, in which case the pointer collet must be reamed out to suit its particular spindle, otherwise the area of contact between the collet and spindle is insufficient for security. If this point is given particular attention failures are unlikely to occur.

When instruments are reading inaccurately, the errors are often found to be uniformly high or low when measured in terms of angular deflection of the pointer. A resetting of the pointer, therefore, would render the instrument quite serviceable. This operation may be performed in the following simple manner—

- (a) Remove the instrument bezel and glass. In most cases the bezel is easily removed. It may be either the screw-on type or (as in the case of some of the older types of pressure gauges and engine speed indicators) attached by three or more screws to the case. In some of the earlier "Smith" type air speed indicators the bezel with a spun-in glass is screwed into the main casting and cemented. In this case it will be

necessary to apply heat in order to soften the cement. This is best performed by the use of a special bezel removing tool in the form of a ring-wrench which can be gently warmed up and clamped on to the bezel for unscrewing, whilst the instrument case is firmly held either by a second operator or in suitable wood block held in a large vice.

(b) Remove the pointer from its spindle, taking care that the spindle is not bent during the process. Most pointers are push-fits on the spindle, and should be withdrawn with a pointer remover—shown in Fig. 67. This is accomplished by placing the recess in the bottom plate of the remover under the pointer collet flange, and screwing down the screw on to the end of the pointer spindle so as to force the collet from the spindle.

Great care should be taken with luminized pointers since the luminous compound is easily dislodged.

(c) Connect the instrument with the standard test instrument and operate the apparatus until the standard reads somewhere about the middle of the scale of the instrument. Tap the instrument so as to overcome the friction and replace the pointer so as to read accurately at this point.

Readings should then be taken throughout the range of the instrument and, when it is confirmed that the pointer is accurately set, it should be lightly but securely tapped on.



POINTER REMOVER

FIG. 67

During the resetting of a pointer, it is important to note whether the dial is adequately secured from moving relative to the instrument case. Unless the dial is secured from rotating, inaccuracies are inevitable.

Painting of Metal Cases. During the overhaul of an instrument it is frequently necessary to repaint its metal case. This is important, since painting is a protective measure against corrosion. Before repainting, the case must be thoroughly cleaned of all old paint, grease, and oil. In an aluminium case this is best done by scraping and papering, and afterwards thoroughly cleaning in petrol. The surface must be free from grease, or flaking of the paint will occur. The case should preferably be spray-painted with a cellulose matt-black lacquer, but if no spraying plant is available it can be brush-painted with any suitable proprietary black enamel or lacquer.

Worn Bearing Holes. Play in the movement of an instrument may be frequently traced to worn bearing holes, and, provided that the wear is only slight, the hole may be closed and re-broached to size, as a temporary measure only. This is effected by the use of a round-ended punch, which should be applied to the surface of the plate round the hole at equal intervals so as to close in the hole to slightly less than is finally required, that is to say, the spindle which the hole normally takes should just fail to enter the hole. The hole should then be carefully broached to the correct size.

Hairsprings. Practically every instrument is fitted with a hairspring, the function of which is to take up backlash in gears, etc. Hairspring collets are usually mounted on the pointer spindles above the pinion, which engages the toothed segment of the movement. Unless a hairspring is correctly fitted and shaped, there is a danger of the spring buckling when under tension, with the result that it is liable to become entangled in the gearing. Most pressure gauges, air speed indicators,

and thermometers are provided with a hairspring guard which prevents this happening.

Hairsprings should, therefore, lie flat, with their coils equally spaced when not under tension.

It may be necessary to fit a new hairspring to an instrument. It is generally possible to obtain hairsprings already fitted to suitable collets, but if it is desired to fit a new hairspring to an existing collet, considerable care is necessary. When the old collet is removed from its spindle and the old spring detached from it, the new spring must be bent at its inner coil, so that when it is pinned the collet will lie in the centre. In order to pin the spring to the collet successfully, care must be taken to see that the pin, together with the spring end, fit the hole in the collet properly, and that the pin is of such a length as not to project unduly from the hole. In pinning the spring it is necessary to have some means of holding the collet tightly. It may be held on a tapered broach or similar tool.

Most instruments are fitted with phosphor-bronze hairsprings on account of the non-rusting and non-magnetic properties of this metal, and it is not desirable to refit steel springs when making replacements, but to take the opportunity to fit ones of phosphor-bronze.

The above remarks do not, of course, refer to the mainsprings of watches, the refitting of which calls for considerable skill and training. In fact, the repair of watches, generally, is best left to a qualified watchmaker.

The adjustments and modifications considered above are generally of a minor character, and are applicable to instruments in general. The following notes refer to certain individual instruments, and deal with repairs and modifications of a major nature. These should not be attempted except by a skilled instrument maker.

Altimeters. The most common cause of failure in an altimeter is the breakage of the fine chain connecting the lever to the arbor on the pointer spindle. This chain is anchored by means of small pins to the pointer spindle arbor at one end, and to a small metal strip at the other; it is usually supplied in lengths by manufacturers, and from these the desired length for an instrument can be cut. Since the smooth working of an altimeter depends to a very large extent on the freedom of the links of the chain, it is not sufficient to refit a chain without previous "suppling." This is done in the following manner.

A polished metal pin of approximately $\frac{1}{16}$ in. diameter is either held horizontally in a vice or driven into the edge of the bench. The chain is slightly oiled, and with one turn round the pin is drawn slowly backwards and forwards at right angles to the pin for two or three minutes. It is then thoroughly cleaned in petrol and dried off. The operation may then be repeated, once or twice only, on the pin in a dry state. If when the chain is fitted there is any tendency towards friction in the links, and the hairspring will not take up the chain smoothly, it has been insufficiently "suppled."

Other faults likely to be found in altimeters are—

- (a) Diaphragm damaged or leaking.
- (b) Deterioration of mainspring.
- (c) Dial zero setting pinion damaged, e.g. stripped teeth.

The pinion can, of course, be replaced without altering the instrument adjustment, but care should be taken to ensure that the dial setting works smoothly, and neither too easily nor too stiffly. It is not desirable to attempt to refit diaphragms or mainsprings, but if this is carried out the

instrument must be allowed ample time to settle down after assembly and before final regulation and test. The diaphragm spring assembly must be levelled up by means of the carriage adjusting screw and roughly ranged. Final and fine adjustments are carried out by means of the regulator screw on the pivoted spindle. In re-assembling an altimeter, special attention should be given to the following points—

1. Steel chain should be supple and work smoothly.
2. Regulator spindle and pointer spindle pivots should be suitably burnished.
3. Transmission link holes must not be elongated or enlarged through wear.
4. Dial adjustment must work smoothly.
5. Pointer must rotate in a plane parallel to the dial.
6. No oil or lubricant to be applied anywhere.
7. The hairspring must be free from corrosion and distortion, and be tight on its spindle.

Boost Gauges. Deterioration of the synthetic rubber washer, which helps to make the joint between the glass and the case airtight, is a frequent cause of failure. This can usually be cured, for a time at any rate, by tightening the bezel. The remarks on the repair and adjustment of the altimeter apply to the boost gauge.

Air Speed Indicator. The principal trouble likely to occur with air speed indicators is the development of leaks. These leaks may occur at the bezel or may be due to strain on the joints or the diaphragm. In the latter case, when a metal diaphragm is fitted, this strain is accompanied by a marked displacement of the pointer from its zero position when no pressure is applied to the instrument.

A bezel leak is best cured by removing the bezel, thoroughly cleaning the threads, and refitting with a new rubber ring before screwing down tightly. In the case of the screwed-in and cemented bezel, a leak may be stopped, as a temporary measure, by the application of shellac. Since a leak at the bezel affects the static side of the indicator only, it is not found seriously to interfere with accuracy of indications, provided it does not exceed, say, 10 m.p.h. in 10 sec. when pressure is applied equivalent to 160 m.p.h., and the static nipple "stopped off." A leak on the static side may become serious, however, if the static side of the indicator is connected up to the altimeter in the cockpit, owing to pressure changes. Most specifications, however, permit a leak not exceeding 15 m.p.h. in 10 secs., when pressure equivalent to 150 m.p.h. is applied and the static nipple "stopped off."

A distorted diaphragm due to excessive pressure does not normally arise in service, but accidental overloading may occur during installation or testing, and distortion may not be apparent until the indicator is tested for accuracy, when it will be found to read high. The total diaphragm movement may be affected so that pointer resetting does not effect a remedy. In this case replacement of the diaphragm is necessary, and a new one should be obtained from the manufacturers of the instrument. Absolute uniformity in physical properties of metal diaphragms is extremely difficult to obtain in manufacture, and to range an instrument with a new diaphragm to agree with the old dial scale markings is frequently outside the range of adjustment of the mechanism. The dial will therefore have to be re-divided. As in the case of the altimeter, the instrument must be allowed to settle down by ageing after assembly and before re-calibration.

The mechanism should be free from friction or undue wear, and the hairspring symmetrical and free from corrosion.

Pressure Gauges. Pressure gauges, like air speed indicators, are occasionally subject to overload pressures which affect the diaphragm or Bourdon tube. The failure of a pressure gauge is often an indication that the Bourdon tube has been badly strained or burst. Traces of oil on the dial or glass also point to a leaking tube. Most pressure gauges are designed to withstand overloads up to 100 per cent of their scale range, so that a burst tube is either accidental or a sign that ageing has taken place.

Bourdon tubes are made, by special processes, of phosphor-bronze or other elastic metal of thickness and section appropriate to the range of the gauge. They are soft-soldered into the casting at the base, which also forms a support for the mechanism and is provided with a connecting hole to the threaded union. The other end of the Bourdon tube is sealed by means of a light cap (soldered in position) bearing a connexion for the linkwork of the mechanism. In fitting a new Bourdon tube to a gauge, a considerable amount of soldering is necessary, and there is a danger that overheating may affect the elastic properties of the metal. It is therefore essential that soldering "irons" of the correct size and shape be used to localize the applied heat. Care is also necessary to avoid either the whole or partial blockage of the connecting hole with solder. Under vibration, loose pieces of solder left inside the tube are liable to be shaken down into the hole and cause a stoppage in service.

A pressure gauge which has been fitted with a new Bourdon tube can, possibly, be readjusted to agree with the original dial, provided that the new tube is of such a thickness of metal and cross-section as to give approximately the same pressure-deflection characteristics as the old one. Small adjustments for ranging are possible by carefully bending the links to increase or decrease the leverage of the quadrant.

In reassembling a gauge, special care must be given to ensure freedom from friction or corrosion in the mechanism, and to see that none of the bearing holes are worn. The hairspring must be fitted symmetrically, and so as to obviate the danger of the spring buckling under tension and fouling the mechanism. A maximum stop is generally fitted. This operates on the Bourdon tube, when the pressure is just greater than the highest scale reading. The stop must be quite definite in its operation.

Engine Speed Indicators. Defects in engine speed indicators are very often indicated by unsteady readings or extreme stickiness of the mechanism. These are mainly due to worn parts or the ingress of oil respectively. Before definitely condemning an indicator, however, it is advisable to inspect carefully the flexible drive, since an old drive, which has been coiled or bent for a considerable period, invariably develops a "whip" which is responsible for unsteadiness of indications in the indicator. In fitting a new inner cable to a drive, the process of soldering the squared connectors, as detailed on page 5, should be followed.

In dismantling an instrument for overhaul, the general precautions already detailed should be carefully observed. The whole mechanism should be thoroughly cleaned and washed in petrol, ball-races should be freed and examined, and the reduction gear overhauled and greased with a suitable non-freezing grease. End adjustment of the main spindle must be carefully made.

The polished portion of the main spindle on which the sliding muff operates must be perfectly clean, and in no circumstances should any

lubricant be applied to this surface. Stickiness will result if this is not observed.

After overhaul, tests should be carried out for the following points and adjustments made, if necessary, for the following—

(a) *Inaccurate Ranging.* This may be due to the tension on the governor spring.

(b) *Differences in Readings with Clockwise and Anti-clockwise Directions of Rotation.* This is generally found to be caused by the quadrant connecting lever taking up a different position in the sliding muff on reversal of rotation.

(c) *Unsteadiness of Readings.* Unsteadiness is due to a number of causes, e.g. worn parts, muff not running truly, unsteadiness in gears, clearance adjustments, etc.

(d) *Friction* and too much difference between readings with increasing and decreasing speeds, due to tightness of moving parts or the presence of oil where it is not required.

Finally, in the assembly of all types of instruments, it is essential for all screws, nuts, etc., to be sufficiently tight to withstand vibration. In many types of instruments small screws and nuts are secured by the application of shellac.

APPENDIX XI

LIST OF CIVIL INSTRUMENT SPECIFICATIONS

THE following Civil Instrument Specifications were issued in June, 1934, with Amendment List No. 39 to Air Publication No.1208, the Airworthiness Handbook for Civil Aircraft.

1. Altimeters.
2. Air Speed Indicators.
3. Pressure Head for use with Air Speed Indicators.
4. Engine Speed Indicators.
5. Pressure Gauges for Oil and Fuel Systems.
6. Oil Temperature Thermometers.
7. Radiator Temperature Thermometers.
8. Turn Indicator.
9. Pilot's Magnetic Compass.

Note. No. 4 was cancelled by Amendment List 46 dated Feb., 1936, and 4A printed on page 125, substituted.

These specifications have recently been reissued under the general title of **Air Ministry Civil Specifications** and should now be referred to as C.S. No. 1, etc. The new issues are substantially the same as the previous issues which appear on the following pages, with the exception that an additional clause requires the instruments to be marked with the maker's name and serial number in a position readily readable when the instrument is installed in an aeroplane. It is also recommended that instruments be marked with the distinguishing number of the specification against which it has been certified, e.g. C.S. No. 4a.

Alterations and additions to these specifications may be made from time to time. The most recent issues can be obtained from H.M. Stationery Office, Kingsway, London, W.C. 2.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 1

ALTIMETERS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General Construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and re-conditioned instruments. 2. (i) (a) The instrument will be tested with the dial upright in a vertical plane at room temperature (10° C. to 20° C.).

(b) The instrument will be lightly tapped before taking readings.

(c) The errors with pressure decreasing and increasing will be found from one continuous test, the pressure being varied at a rate equivalent to 1,000 ft. per minute and being kept constant for one minute at the pressure corresponding to the maximum range of the particular instrument,

1		2	3		4
Barometer inches		Height in feet	Permissible Errors 0-20,000 feet range		
Iso.	I.C.A.N.		Up	Down	
29.99	29.99	0	0		+ 150
28.91	28.93	1,000	- 40		+ 150
27.87	27.89	2,000			+ 150
26.86	26.88	3,000	- 60		+ 150
25.89	25.91	4,000			+ 200
24.95	24.96	5,000			+ 200
24.05	24.04	6,000	- 80		+ 250
23.18	23.15	7,000			+ 250
22.35	22.28	8,000			+ 300
21.54	21.44	9,000	- 100		+ 300
20.76	20.63	10,000			+ 300
20.01	19.84	11,000			+ 350
19.29	19.08	12,000			+ 350
18.59	18.34	13,000	- 150		+ 350
17.92	17.62	14,000			+ 350
17.27	16.93	15,000			+ 400
16.65	16.26	16,000			+ 400
16.05	15.61	17,000			+ 400
15.47	14.98	18,000	- 200		+ 400
14.91	14.37	19,000			+ 400
14.37	13.78	20,000			+ 400

(ii) (a) The instrument shall be so adjusted as to indicate the heights shown in column 2 of the table on page 119 at the barometric pressure shown in column 1 within the tolerances shown in the table (columns 3 and 4).

(b) The movement is to be compensated for temperature changes between -5°C. and $+35^{\circ}\text{C.}$

(c) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this sub-paragraph.

(d) The maximum difference between the readings at any one pressure with pressure increasing and decreasing is not to exceed 400 ft.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10°C. to 20°C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those permitted in paras. 2 (ii) (a) and (2) (ii) (d) above.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 2

AIR SPEED INDICATORS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

(ii) The instrument shall be capable of withstanding an overload pressure of $33\frac{1}{3}$ per cent in excess of the pressure equivalent to the maximum scale reading.

Method of testing and permissible errors for new and re-conditioned instruments. 2. (i) (a) The instrument will be tested with the dial upright and in a vertical plane at room temperature (10°C. to 20°C.), and the figures shown in the tables will be used to determine the air speed from the pressure difference.

(b) The instrument will be lightly tapped before taking readings.

(ii) (a) The calibration shall be according to either one or other of the following relations—

(1) $P = 0.012504 V^2 (1 + 0.43 V^2 \times 10^{-6})$ where V is the air speed in miles per hour, and P is the pressure difference in mms. of water at 15°C.

(2) $P = 0.016580 V^2 (1 + 0.57 V^2 \times 10^{-6})$ where V is the air speed in knots, and P is the pressure difference in mms. of water at 15°C.

(3) The pressure differences are as follows—

For Speed in Miles per Hour

Air Speed m.p.h.	Pressure Difference mms.	Air Speed m.p.h.	Pressure Difference mms.	Air Speed m.p.h.	Pressure Difference mms.
40	20.0	110	152.1	180	410.7
50	31.3	120	181.2	190	458.3
60	45.1	130	212.8	200	508.7
70	61.4	140	247.1	210	561.8
80	80.2	150	284.0	220	617.6
90	101.6	160	323.6	230	676.3
100	125.6	170	365.8	240	737.9

For Speed in Knots

Air Speed	Pressure Difference	Air Speed	Pressure Difference	Air Speed	Pressure Difference
knots	mms.	knots	mms.	knots	mms.
35	20.3	100	166.7	170	487.0
40	26.55	110	202.0	180	547.1
50	41.5	120	240.7	190	610.9
60	59.8	130	282.9	200	678.2
70	81.5	140	328.6	210	749.5
80	106.5	150	377.8		
90	134.9	160	430.6		

(b) *Ranging.* The instrument shall be so adjusted as to indicate at room temperature the air speeds at the pressure differences shown in the tables with a tolerance of ± 2 m.p.h. or knots as may be appropriate.

(c) The error at any temperature between -5° C. and $+35^{\circ}$ C. shall not exceed ± 3 m.p.h. or knots as may be appropriate (± 5 below 40 m.p.h.).

(d) The difference of reading due to a change of position of the instrument between the normal and 90° therefrom must not exceed, at any point on the scale, 2 m.p.h. or knots as may be appropriate (above 40).

(e) The pressure and static chambers must be sufficiently free from leaks, both to each other and to the outer atmosphere so that when a pressure difference of approximately 280 mms. of water is applied, and then shut off, the pointer does not fall more than 15 m.p.h. or 13 knots in 10 seconds.

(f) The constriction in the static nipple shall not be less than $\frac{1}{16}$ in. in diameter.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible error under these conditions shall not exceed 5 m.p.h. or knots as may be appropriate.

(iii) The permissible leakage shall not be greater than that specified in para. 2 (ii) (e) above.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION NO. 3

PRESSURE HEAD FOR USE WITH AIR SPEED INDICATORS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The pressure head shall be constructed in accordance with the drawings accompanying this specification, or other approved form.

(ii) There shall be no leaks on either the static or pressure pipes when tested under a pressure of 2 lb. per square inch.

Note. The Drawings are not reproduced.

C.I.S. No. 4A

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 4A

ENGINE SPEED INDICATORS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

2. *Electrical engine speed indicators. Compass interference.* When an electrical indicator is placed in any position within 10 in. from the nearest edge of the case to the nearest edge of a compass, the latter shall not deflect more than 2°. Any variation of current in the complete set shall not cause any deviation of the compass. For the purpose of the test a type 253 Compass may be used.

3. *Method of testing and permissible errors for new and reconditioned instruments.*

(i) The instrument is liable to be tested under any combination of the following circumstances—

- (a) With the dial vertical or horizontal.
- (b) With the whole or any part of the equipment at any temperature between - 5° C. and + 35° C.
- (c) With speed increasing or decreasing.
- (d) With the drive (or generator) running in either direction.
- (e) Before or after 150 hours' running.

(ii) The instrument will be lightly tapped before taking readings.

(iii) With the dial vertical and the instrument at room temperature the error shall not exceed ± 25 r.p.m.

(iv) Under no combination of circumstances as outlined in para. 3 (i) above shall the instrument be in error by more than 40 r.p.m.

(v) The instrument shall be capable of running for 300 hours without additional lubrication.

(vi) The errors quoted in sub-paras 3 (iii) and 3 (iv) refer to a range of 2,000 r.p.m. between minimum and maximum readings. For other ranges, the errors shall be altered *pro rata*, e.g. for a range of 500 to 3,500 r.p.m. the permissible errors quoted would be increased by 50 per cent.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those permitted under para. 3, sub-paras. (iii) and (iv) above.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 5

PRESSURE GAUGES FOR OIL AND FUEL SYSTEMS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

(ii) The overloading capacity of each instrument shall be 100 per cent, i.e. the maximum load shall be double the maximum scale reading.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (a) The instrument will be tested with the dial upright in a vertical plane at room temperature (10°C. to 20°C.).

(b) The instrument will be lightly tapped before taking readings.

(ii) (a) The error at any point of the scale shall not exceed the amount stated in column 2 of the following table—

1	2	3	4
Range of Instrument lb./sq. in.	Type of Error		
	Ranging lb./sq. in.	Temperature lb./sq. in.	Cumulative lb./sq. in.
0-10	± 0.5	± 0.8	1.0
0-25	± 1.0	± 1.5	2.0
0-50	± 2.0	± 3.0	4.0
0-100	± 3.0	± 4.5	6.0
0-200	± 5.0	± 7.5	10.0

(b) The reading shall be taken both with increasing and decreasing pressure and the test for the whole range of the instrument shall occupy approximately 20 minutes.

(c) After application of the maximum load for a period of 5 minutes, the instrument must not show any alteration in calibration exceeding 50 per cent of the permissible calibration error. Any alteration must entirely disappear within 24 hours after removal of the pressure.

(d) In performing this test the operations should be carried out in the following sequence—

1. A normal full scale range check with both increasing and decreasing pressure.

2. Overload to the maximum pressure.

3. Take readings with decreasing pressure for comparison with tests prior to overload.

(iii) The error at any point of the scale at any temperature between -5°C. and $+35^{\circ}\text{C.}$ shall not exceed the amount stated in column 3 of the above table.

(iv) The difference in reading at any part of the scale due to change of position of the instrument between normal and 90° therefrom must be such that errors are still within the limit given in column 4 of the above table.

(v) The instrument may be submitted to a pressure equivalent to 75 per cent of the maximum scale reading for a period not exceeding 6 hours. The final readings must be such that the errors are still within the limits given in column 4 of the above table.

(vi) The total error resulting from the above causes taken together must not exceed the amount stated in column 4 of the above table.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10°C. to 20°C.) and with the instrument in flying position.

(ii) The permissible error under these conditions shall not exceed twice the amount given in column 4 of the above table. The error at zero, however, shall in no case exceed ± 1 per cent of the full-scale reading of the gauge.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 6

OIL TEMPERATURE THERMOMETERS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (a) The instrument will be tested with the dial upright in a vertical plane.

(b) The instrument will be lightly tapped before taking readings.

(ii) (a) At no part of the scale on either a falling or a rising temperature shall the error in calibration exceed the limits -1°C. to $+2^{\circ}\text{C.}$

(b) With the capillary and/or the gauge at any temperature between -5°C. and $+35^{\circ}\text{C.}$ the readings shall not differ by more than 2°C. from that with the capillary and/or the gauge at 15°C. The bulb temperature at which this test will normally be applied may vary from 0°C. to 20°C.

(c) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this clause.

(d) Errors due to a difference in level between the bulb and the indicator shall not exceed 0.05°C. per foot of height.

(e) There shall be no appreciable error due to a change of external pressure down to 20 in. of mercury.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10°C. to 20°C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those specified in para. 2 (ii) (a) and (b) above.

Note. Vapour pressure transmitting types do not satisfy Clause (ii) (e) of this specification.

S.I.C. No. 7

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 7

RADIATOR TEMPERATURE THERMOMETERS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (a) The instrument will be tested with the dial upright and in a vertical plane.

(b) The instrument will be lightly tapped before taking readings.

(ii) (a) The error of calibration at any point shall not be negative or exceed $+ 2^{\circ}$ C. at an atmospheric pressure approximately equivalent to 760 mms. of mercury.

(b) With the capillary and/or the gauge at any temperature between $- 5^{\circ}$ C. and $+ 35^{\circ}$ C. the reading shall not differ by more than 2° C. from that with the capillary and/or the gauge at 15° C. The bulb temperature at which this test will normally be applied may vary from 55° C. to 73° C.

(c) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this clause.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those specified in para. 2 (ii) (a) and (b) above.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATION No. 8

TURN INDICATOR

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) *Principle.* The instrument shall consist of a gyroscope, mounted in a horizontal gimbal ring which is pivoted about an axis normal to the plane of the dial and suitably damped. Angular movement of the gimbal ring against suitable spring or gravitational restraint shall be indicated by a pointer on the dial of the instrument. The gyroscope may be electrically or air driven. In the latter case, a venturi tube capable of giving the required air flow when fitted to the aircraft on which the instrument is to be used shall be supplied. The lateral component of apparent gravity shall be indicated on the dial of the instrument either by a pointer connected to an air damped pendulum, or a bubble type cross level. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, pointers, etc., shall be secured against working loose under vibration.

(ii) *Rotor.* The rotor shall be balanced about its axis of spin.

(iii) *Sensitivity control.* In the case of a spring-controlled instrument, a suitable spring shall be attached to one end of the gimbal ring and at the other end to means whereby the spring tension may be varied to obtain the required sensitivity. This adjustment need not be operable from the outside of the case when mounted on the instrument board.

(iv) *Bearings.* Adjustable ball bearings shall be fitted to the gyro rotor and to the horizontal gimbal ring. The adjustment shall be locked in position when the required setting has been obtained.

(v) *Air filler.* In the case of air driven instruments, an efficient and readily detachable filter shall be fitted on the air inlet leading to the jet, so designed as to prevent the ingress of dust.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) *General.* (a) Unless otherwise specified the instrument shall be tested in the normal position at room temperature (10° C. to 20° C.). The normal position is that in which the dial is upright and in a vertical plane.

(b) Light tapping of the instrument case is permissible during test.

(ii) *Sensitivity.* (a) The sensitivity of the instrument at room temperature (10° C. to 20° C.) shall be such that a pointer deflection of 0.1 in. is obtained for a rate of turn of 45° per minute $\pm$ 20 per cent.

(b) The instrument shall be so adjusted that the scales are reasonably linear.

(c) At any temperature, other than room temperature, between

- 5° C. and + 35° C. the tolerance on the rate of turn to produce a pointer deflection of 0.1 in. shall be 10 per cent on the actual calibration at room temperature.

(iii) *Venturi*. In the case of air driven instruments, the venturi shall be designed to give the above sensitivity at a speed of the venturi through the air of 100 m.p.h. For the information of manufacturers, the suction likely to be expected from a single venturi of the usual type employed for turn indicators is about 1.5 in. of mercury at this speed. It is to be noted that this figure is dependent upon the size of the jet in the turn indicator.

(iv) *Gyro*. With the gyro rotor spinning or stationary there shall be no apparent deflection of the pointer from zero when the indicator is rotated about an axis normal to the plane of the dial.

(v) *Inclinometer unit*. (a) The range of this unit shall be $\pm 20^\circ$.

(b) Within the temperature range of - 5° C. to + 35° C. the instrument shall be so adjusted as to indicate the inclination with a tolerance of ± 5 per cent of the total range.

(c) In the case of the bubble type inclinometers the liquid shall not separate, freeze or become so viscous as to cause sluggishness of the bubble movement at a higher temperature than - 5° C. The consistency shall be such that the bubble, while not easily broken up under vibration, will rapidly coalesce say within 2 seconds approximately of the cessation of an excessive vibration.

(vi) *Damping*. (a) The damping of the turn indicator unit and the pendulum inclinometer unit shall be such that, after any given displacement, the pointer shall pass beyond the zero mark by an amount not exceeding one quarter of the initial displacement. This test shall be carried out at room temperature.

(b) The damping of the bubble type inclinometer unit shall be such that from a full scale displacement the bubble comes to rest not more than 4 seconds after the instrument has been returned to the zero position. This test shall be carried out at room temperature.

(vii) *Lubrication*. The instrument is required to function correctly for 300 hours without additional lubrication.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The method of testing shall be as specified under para. 2. The tests will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall be 25 per cent greater than those specified in para. 2, unless the inclinometer is of the bubble type, in which case no increase is admissible.

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATIONS No. 9

PILOT'S MAGNETIC COMPASS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

1. The directional error of the magnet system of card shall not exceed 1°
2. The magnet system shall be constructed so that its tilt will not exceed 3° anywhere between the latitudes of 60° N. and 60° S. In England it shall be north end down by an angle not exceeding 2°
3. The magnet system shall be free to revolve when the bowl is tilted 15°
4. When the magnet system is released from rest at a deflection of 10° and at normal temperature of 15° C. the frictional error shall not exceed 1°
5. The ratio

Magnetic moment in c.g.s. units	
the weight in grammes of the magnet system	
in the compass liquid	
shall not be less than	10
6. When at normal temperature of 15° C. the magnet system is released from rest at 90° deflection the time of swing through 85° shall not be less than 6 secs.
7. When at normal temperature of 15° C. the magnet system is released from rest at 30° deflection the overswing beyond zero deflection shall not exceed 4°
8. Swirl tests—
 - (i) When the compass bowl is rotated through 180° in 30 seconds the deflection shall not exceed . . . 10°
and the time to return to within 5° shall not exceed . . . 20 secs.
 - (ii) When rotated through 180° in 15 seconds the deflection shall not exceed 20°
and the time to return shall not exceed 30 secs.
9. The filling liquid shall be clear and free from impurity or discoloration. It shall not freeze above -35° C.
10. The expansion arrangements provided shall be adequate to deal with a temperature range from -25° C.
to
+ 50° C.

11. The compass liquid shall remain free from bubbles when kept for half an hour in a sealed chamber under a reduced air pressure equivalent to 10 in. of mercury.
12. The anti-vibrational suspension of the compass shall be designed so that no deflection of the card or magnet system will result from subjecting the compass to horizontal vibration of any frequency up to 2,000 p.m. and a total amplitude not exceeding 2 mm.
13. The paint used inside the compass bowl shall not discolour, blister, crack, peel or otherwise deteriorate under the prolonged action of the compass liquid.
14. The compass shall be of thoroughly sound manufacture and constructed of suitable materials. It shall be in every way fit for the service for which it is intended and likely to remain in full efficiency for a period of at least 12 months.
15. In addition to conforming to the conditions specified above, no compass shall contain any features or characteristics which, in the opinion of the Air Ministry, are considered to be objectionable or disadvantageous.
16. In the event of a compass with unusual features being sent for examination, the Air Ministry reserve the right of adding to or amending these conditions in order to embrace all details of the compass in question.

OFFICIAL PUBLICATIONS

1. *The Airworthiness Handbook.* (A.P. No. 1208.)
2. *General Instrument Equipment for Aircraft.* (A.P. No. 1275.)
3. *Manual of Air Pilotage.* (A.P. No. 1234.)
4. *Air Ministry Civil Specifications.*

The above are Air Publications, published by H.M. Stationery Office, Kingsway, W.C.2.

G5280

AERONAUTICAL ENGINEERING SERIES

GROUND ENGINEERS

A Series of Nine Volumes covering the Technical Requirements of Ground Engineers Preparing for their Licences.

Each in medium 8vo.

AERO ENGINES

Inspection of Before Flight. "C" Licence.

By R. F. BARLOW. 36 pp. Second Edition. 2s. net.

AERO ENGINES

Inspection of During Manufacture, Overhaul, and Test. "D" Licence.

By A. N. BARRETT, A.M.I.A.E., A.F.R.Ae.S. 136 pp. Sixth Edition. 3s. 6d. net.

INSTRUMENTS

Repair, Overhaul, Testing, and Calibration of Aircraft and Aero-engine Instruments. Adjustment, Installation, and Compensation of Compasses in Aircraft. Category "X" Licence.

By R. W. SLOLEY, M.A. (Camb.), B.Sc. (Lond.). 133 pp. Third and Revised Edition. 5s. net.

THE RIGGING, MAINTENANCE, AND INSPECTION OF AIRCRAFT

Covers the Requirements of the "A" Licence.

By W. J. C. SPELLER. 130 pp. 3s. 6d. net.

INSPECTION OF AIRCRAFT AFTER OVERHAUL

Category "B" Licence.

By S. J. NORTON, Assoc.M.Inst.C.E., A.F.R.Ae.S. 113 pp. 3s. 6d. net. Fourth Edition.

ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

Including the Repair, Overhaul, and Testing of Magnetos. "X" Licence.

By S. G. WYBROW, A.M.I.E.E., A.M.I.M.E. 181 pp. Fourth Edition. 5s. net.

THE AIRCRAFT BENCH FITTER

By WILLIAM S. B. TOWNSEND. 72 pp. 3s. 6d. net.

NOTES ON SUPERCHARGING FOR GROUND ENGINEERS

By C. E. JONES. 33 pp. 3s. net.

THE DEVELOPMENT OF SHEET METAL DETAIL FITTINGS

By WILLIAM S. B. TOWNSEND. 47 pp. 2s. 6d. net. Second Edition.

P I T M A N

66260

